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WT-627

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Report to the Scientific Director

BLAST-WAVE MASS-MOTION MEASUREMENTS

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By

Daniel F. Seacord, Jr.

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Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico
June 1953

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ABSTRACT

Operation Ivy was instrumented for the mass-motion method of pressure measurement in a manner similar to that used on Operations Buster-Jangle and Tumbler-Snapper. Low-altitude pyrotechnic mortar bursts and high-altitude gun bursts (on Mike only) labeled the air for photographic recording.

The methods of instrumentation are described; the method of data analysis is outlined; and derived data on time of arrival, peak material velocity, peak shock velocity, and peak overpressure are presented in tabular and graphical form. Appendixes present meteorological and ballistic data and calculations.

An outstanding conclusion of the experiment is the lowness of peak overpressures near the surface compared with the peak overpressures at altitudes up to 25,000 ft because of the effect of atmospheric inhomogeneity at long ranges.

The mass-motion technique offers a useful diagnostic tool for the determination of total hydrodynamic yield.

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Timing systems for activating the instrument stations, as well as all photography and film processing, were provided by Edgerton, Germeshausen & Grier, Inc.

The Naval Ordnance Plant, Pocatello, Idaho, performed an outstanding service in the preparation and packaging for overseas shipment of the 3-in. 50-caliber guns.

The Program Director, Program 6, Francis B. Porzel, was the originator of the mass-motion method; his continued interest and advice are greatly appreciated.

[redacted]

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE OF EXPERIMENT

The desirability of obtaining true free-air pressure measurements has long been recognized; Project 6.2 instrumented Mike and King shots for this purpose. A true free-air pressure measurement is defined as one that is free from such perturbing factors as measuring instruments, structures, aircraft, or reflection from the surface of the earth.

A basic method for obtaining such a measurement involves labeling a parcel of air with visible particles and photographing their motion under the influence of the blast wave. Photographic analysis of the motion, together with basic hydrodynamic relations, determines the pressure value at that point.

By placing the measurement points at various ranges from the nuclear detonation, material velocity-distance, shock velocity-distance, and pressure-distance curves are obtained. Furthermore, since the first motion of the labeled air indicates the time of arrival of the blast wave at that point, a time-of-arrival curve results from the measurements.

Heretofore, this type of pressure measurement has been limited to the region close to the ground, i.e., up to 1000 ft. Mike shot was instrumented from the surface to an altitude of 25,000 ft in an attempt to determine any asymmetry in the pressure field as the blast wave progressed through an increasingly rarified atmosphere.

A long-range project, utilizing data obtained on this operation as well as data from previous operations, consists in the derivation of pressure-time curves from the mass-motion method. The large number of data points, coupled with time and manpower limitations, has precluded such analysis to date.

1.2 MASS-MOTION METHOD AND PRIOR DEVELOPMENT

The broad underlying purpose of the mass-motion method of measuring hydrodynamic variables is treated elsewhere.[1] The method, in general, consists in placing a small volume of visible smoke particles at a given position in space at a given time relative to a nuclear detonation; its subsequent motion, when struck by the blast wave, is recorded photographically. The analysis of the film record provides data on the time of shock arrival and the displacement of the volume of labeled air as a function of time. This measurement of mass motion, together with meteorological data, may then be converted into a value of overpressure in the blast wave.

Several methods of labeling the air for photographic recording have been investigated during previous operations. The two methods[1] utilized by Operation Buster-Jangle were (1) a smoke plume produced by a JATO unit and (2) an "aerial salute," a commercial pyrotechnic producing a smoke puff in the air several hundred feet above the ground. In addition to these

methods, Operation Tumbler-Snapper included a feasibility test of antiaircraft guns for producing smoke puffs at higher altitudes.[2] Experience on these operations showed that the pyrotechnic smoke puff suited the low-altitude measurement and that the antiaircraft shell, of the proper smoke composition, could be used for high-altitude measurements.

REFERENCES

1. D. F. Seacord, Jr., Blast Measurements, Part III, Blast-wave Material-velocity Measurements, Buster-Jangle Project 10.10 Report, WT-415, March 1952.
2. D. F. Seacord, Jr., Blast Measurements, Part I, Blast-wave Material-velocity Measurements, Tumbler-Snapper Projects 19.2a-f Report, WT-556, August 1952.

CHAPTER 2

LOW-ALTITUDE INSTRUMENTATION

2.1 REEF STATIONS

In order to extend the low-altitude stations to the high-pressure region on Mike shot, the four stations closest to ground zero were located on the reef. For reasons of convenience and to cause least interference with other projects, the mortar line extended out the seaward reef northeast of Elugelab. Figure 2.1 shows the location of these stations in relation to ground zero. Reef Stations 620.01 to 620.04 were at ranges of 4430, 5900, 8250, and 11,490 ft from zero, the average altitude of the mortar bursts was 350 ft.

Each station consisted of a steel pipe embedded in a concrete block which, in turn, was embedded in the reef; the steel pipe extended 8 ft above high-tide level and was provided with two 6-in.-square steel platforms 2 ft from the top. Holmes and Narver (H&N) drawing No. 6128-Q-3 gives the construction details. Submarine cable was laid to each station from the nearest EG&G timing station on the Bogon-Elugelab complex. Timing relays and battery power supply were located in the timing station, the seaward end of the cable was connected to the mortar at each station, and the −5 sec signal transmitted to the station fired the mortar. Figure 2.2 illustrates the firing system for the reef stations.

To complete the preparation of the station for firing necessitated mounting a pressed cardboard mortar on the platform and securing it to the steel pipe, inserting the mortar charge, and connecting the firing squib to the timing cable. The charge and mortar were weatherproofed by wrapping with aluminum foil which effectively kept the stations watertight; the location of instruments at 6 ft above high-tide level minimized dampening due to spray.

All units functioned perfectly during several dry runs and at shot time. Each station could be serviced in less than 5 min, and the chain of four were usually covered in about an hour, utilizing a DUKW for transportation across the reef.

2.2 RAFT STATIONS

To extend the low-altitude instrumentation out to the low-pressure region, five raft stations plus a station on Mack were installed. These were Stations 621.01 to 621.06, located at ranges of 15,900, 21,400, 30,130, 37,200, 47,710, and 68,000 ft from zero for Mike shot (Fig. 2.1). A seventh station was located on Parry at a range of 114,070 ft. For King shot, six rafts, extending from the north tip of Runit westward into the lagoon, were used.

The basic raft station was a 10- by 12-ft planked structure supported on each corner by two 50-gal drums. In the center of the raft was mounted a 4-ft-high platform designed to accommodate the mortar, power supply, and radio timing equipment. The raft construction details are given by H&N drawing No. 6141-Q-3. Figure 2.3 is an over-all view of a typical raft.

Since it was impractical to run timing cables to each raft in the lagoon, a radio timing

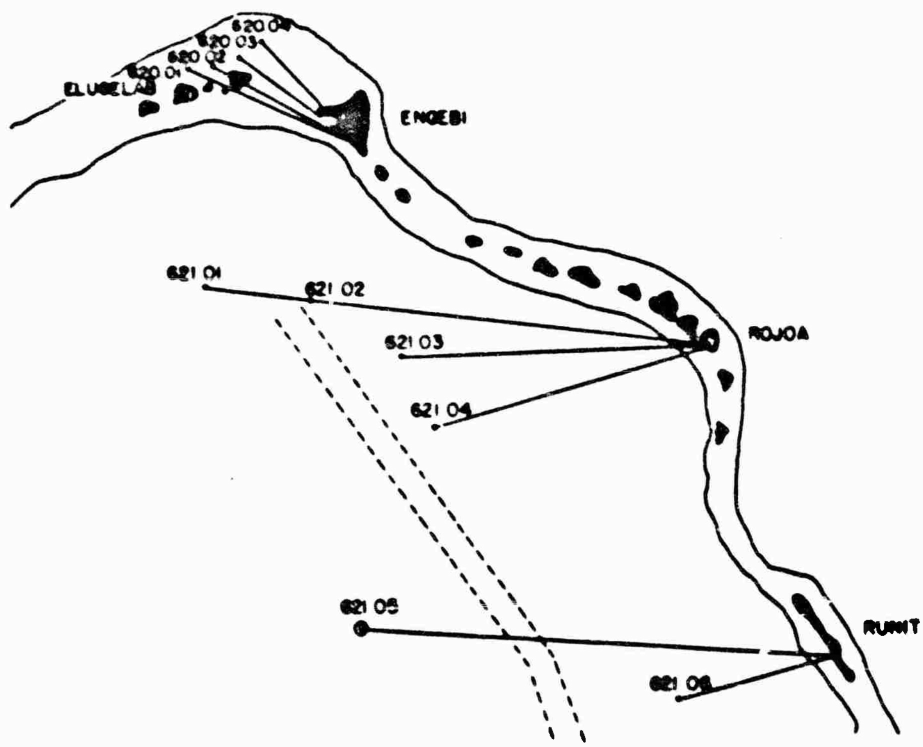

Fig. 2.1—Location of reef (620 series) and raft (621 series) stations.

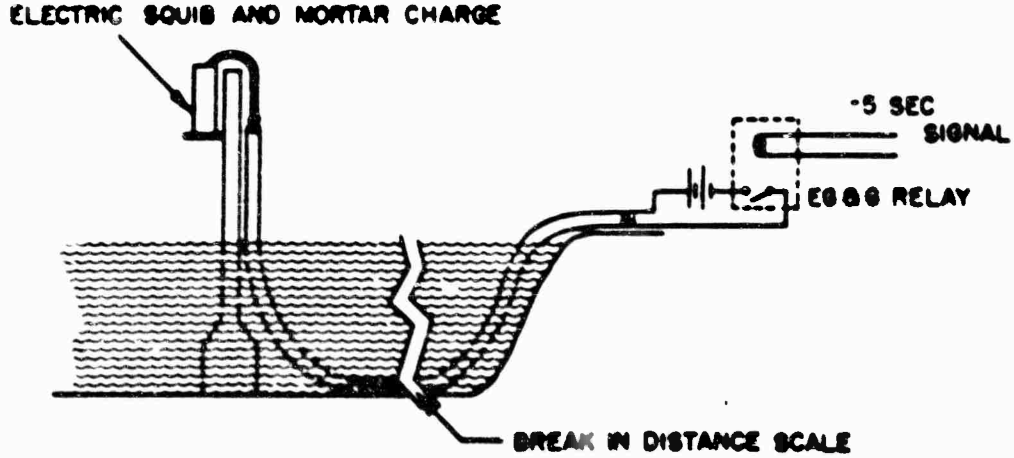

Fig. 2.2—Reef mortar firing system.

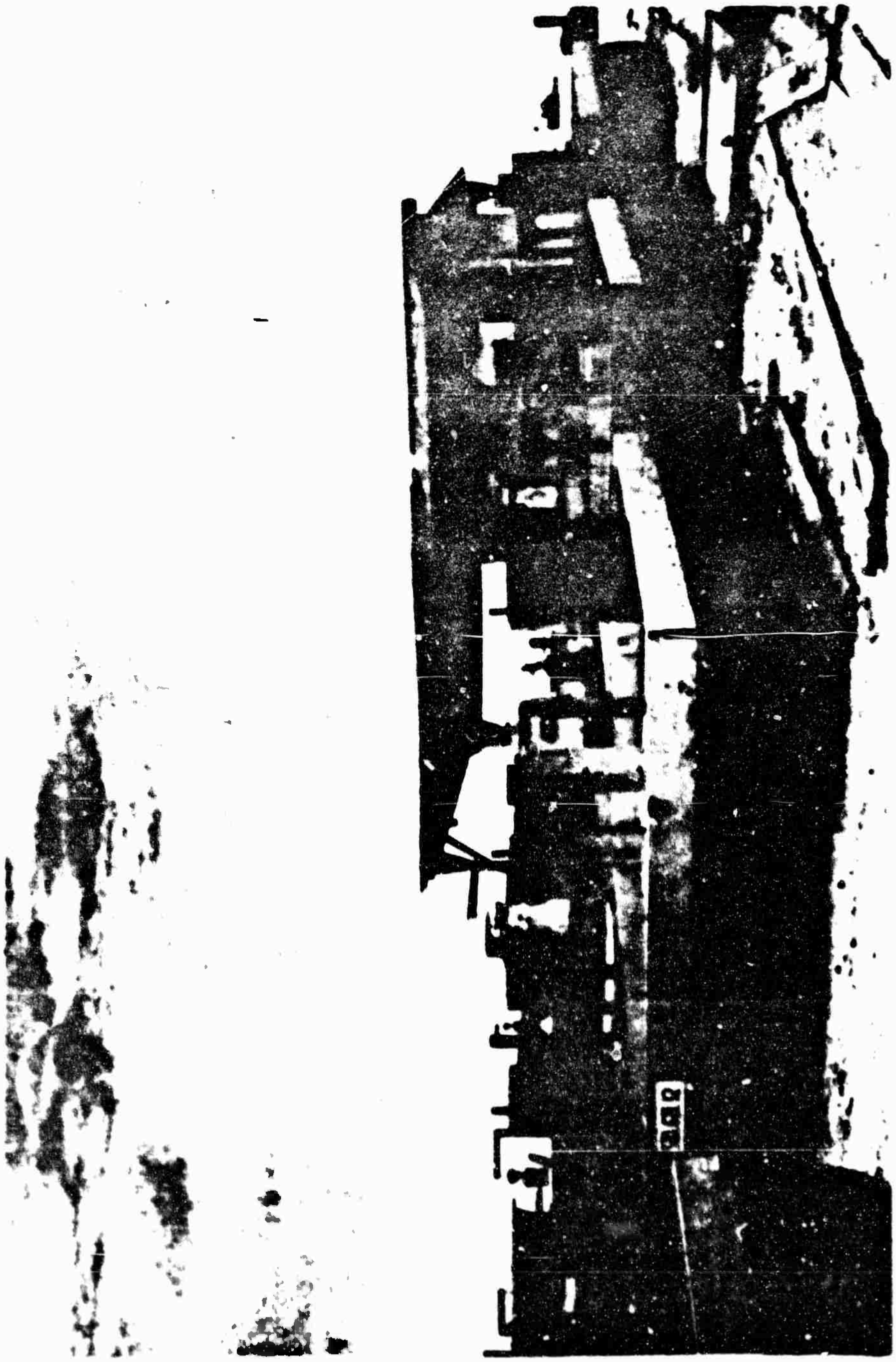

Fig. 2.3—Mortar raft.

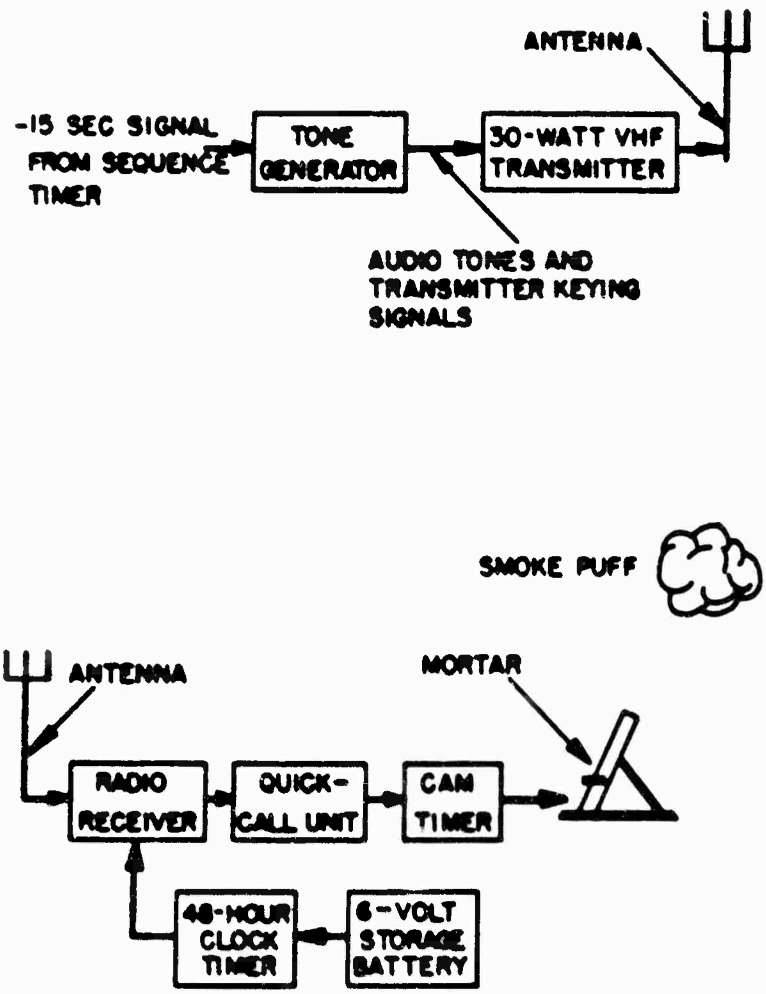

Fig. 2.4—Raft radio firing system (EG&G photograph).

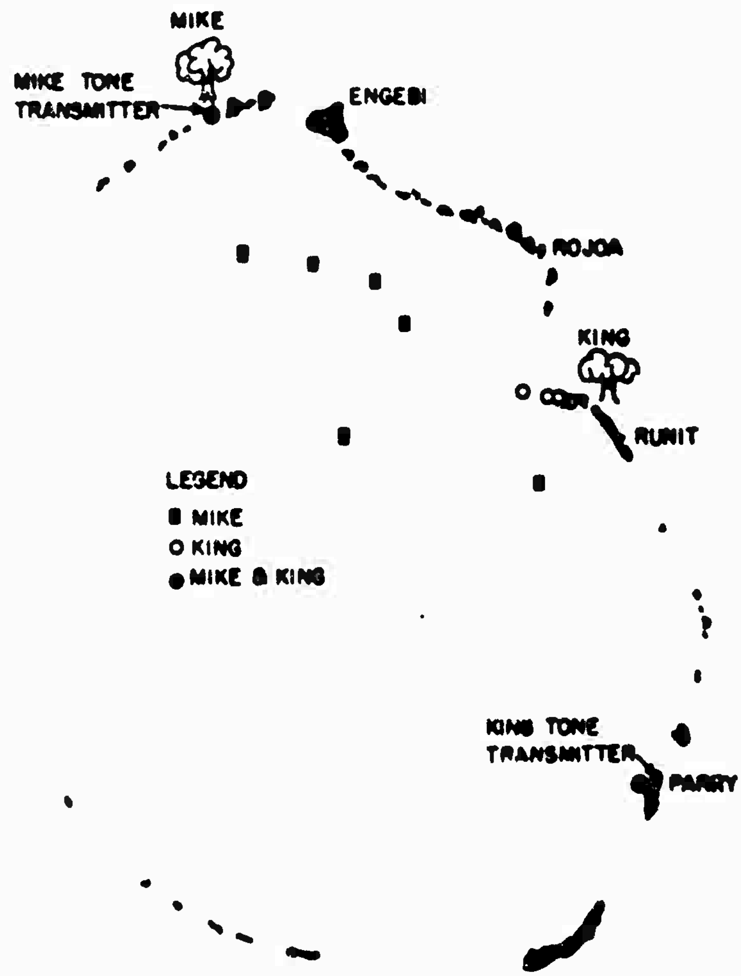

Fig. 2.5 — Location of tone transmitters (EG&G photograph).

system was developed by EG&G for installations such as this. Each raft was equipped with a receiver, variable delay timer, and mechanical clock for activating the unit at about 1 hr before shot time. Figure 2.4 is a schematic drawing of the radio firing system, and Fig. 2.5 shows the location of the tone transmitters with respect to the rafts. The delay timer was necessary to provide a suitable delay between receipt of the signal and the firing of the mortar. Since these stations extended to a considerable range, the smoke puff would have been dispersed at shock arrival if a delay network had not been incorporated in the firing system.

The detailed preparation of the raft stations for the dry run and for the shot is of interest. The mounting plate which held the mortar, radio receiver, and storage battery weighed approximately 60 lb and was extremely unwieldy, especially on such an unstable platform as a raft moored in the lagoon. It was believed that the installation would be simplified by mooring the raft after the radio and mortar had been mounted on the raft. An LCT was used for transporting the rafts to their mooring buoys; a crane, for depositing the raft alongside the buoy; and an LCM, for the actual mooring operation. Formidable as it sounds, the experience achieved on the mooring of the rafts for the dry run allowed the final installation of six stations to be made in less than 5 hr after loading the rafts aboard the LCT at Parry. The H&N personnel handling the crane and boats became so proficient that a maximum of 10 min at each station was required to place the raft in the water, tow it to its buoy, moor it, load the mortar, make the final electrical connections, and start for the next station.

Weather protection for the mortar and charge was similar to that used on the reef stations — aluminum foil wrapping with a rupturable foil cover over the mortar. The timing units were encased in steel boxes with gasketed lids. Each mortar charge was aluminum-wrapped to minimize chances of detonation of the charge during its time of flight since several of the stations were at ranges such that the charge would be in its upward trajectory during the period of high thermal-radiation rates from the nuclear detonation.

CHAPTER 3

HIGH-ALTITUDE INSTRUMENTATION

3.1 GUN STATIONS

That portion of the mass-motion experiment designed to measure hydrodynamic variables at high altitudes above the surface of the earth required the installation of a battery of 10 anti-aircraft guns on Engebi.

Twelve dual-purpose 3-in. 50-caliber guns were obtained from the Naval Ordnance Plant (NOP), Pocatello, Idaho; 10 were installed on Engebi, and two complete units were retained on Parry as spares or for spare parts. Figure 3.1 is a general view of the weapon. Detailed information on the Mark 22 mount may be found in reference 1. The units were completely disassembled, cleaned, reassembled, and prepared for overseas shipment by the NOP, Pocatello. Each unit was shipped in two containers, one crate containing an assembled mount and slide and one containing the barrel-and-breech assembly. The preparation accomplished by the NOP greatly facilitated field installation. The mount was installed on a concrete base plate, and the insertion of the barrel required about 10 min. The concrete base plate, constructed by H&N, is shown on their drawing No. 8129-J-3. A view of the 10-gun battery on Engebi is shown in Fig. 3.2.

Figure 3.3 shows the relation between the gun stations, shot island, and the line of gun bursts (projected in plan).

The guns were equipped with an electrical firing system. Firing was accomplished on an EG&G timing signal by placing an EG&G relay in series with the battery power supply of the gun and the firing solenoid; the firing key of the gun was locked closed. Figure 3.4 is a schematic drawing of the firing circuit for each gun.

3.2 AMMUNITION

Special ammunition was provided by the Naval Ammunition Depot (NAD), Mare Island, for this project. A dense white puff of smoke was desired as the object to be photographed, and, since white phosphorus shells were not available for this weapon, a search was made for a suitable white-smoke compound. Research by Picatinny Arsenal had indicated various colored-smoke compounds.[1] Several rounds of these colored smokes were prepared by the Bureau of Ordnance and were tested in the field at the Naval Proving Ground, Dahlgren, Va., on July 7 to 10, 1952. To simulate proposed ranges and camera resolution expected at Eniwetok, each burst was photographed with a 16-mm camera with a lens of 1-in. focal length. Rounds of red, white, yellow, and green smoke were detonated at ranges of 2000 to 5000 yd. Photographic results showed that the white-smoke composition was best suited to the purpose of the project. Consequently, NAD, Mare Island, prepared 70 rounds of fixed ammunition having the following

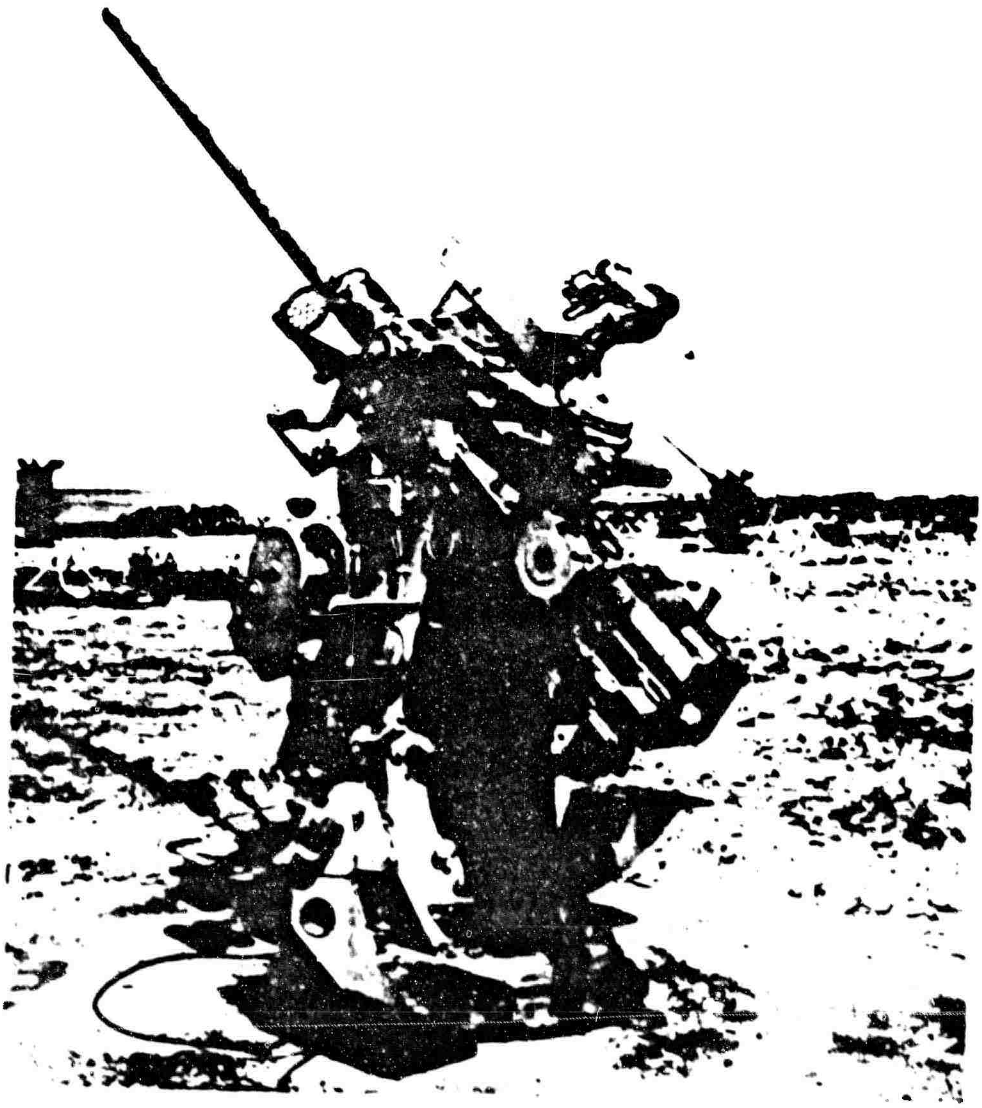

Fig. 3.1 — Dual-purpose 3-in. 50-caliber gun.

Fig. 3.2—Gun battery on Engebi.

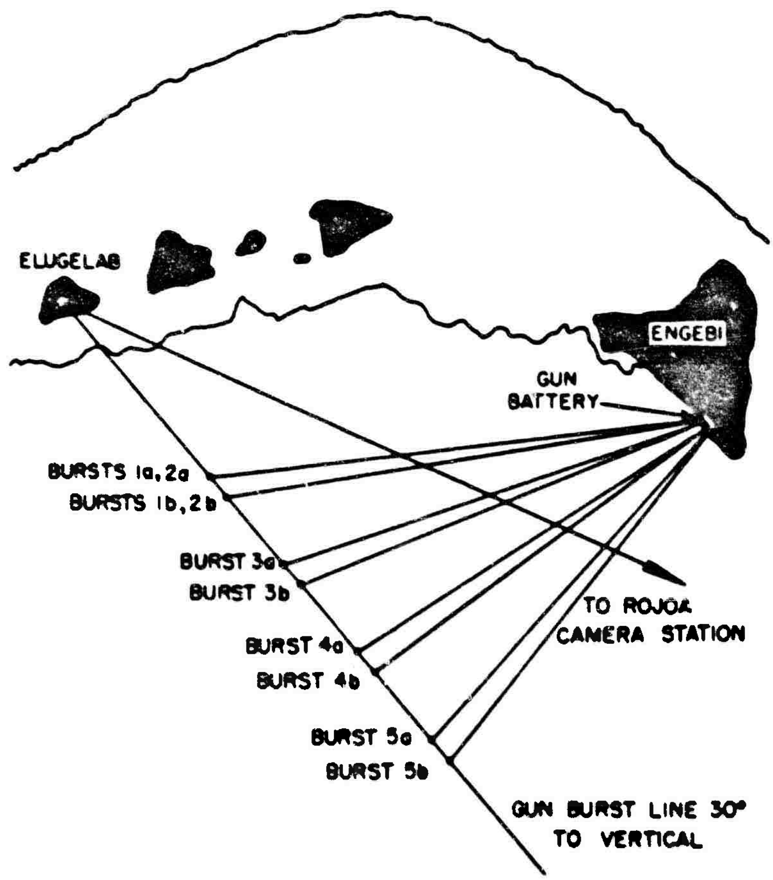

Fig. 3.3 — Location of gun stations, shot island, and line of gun bursts (plan view).

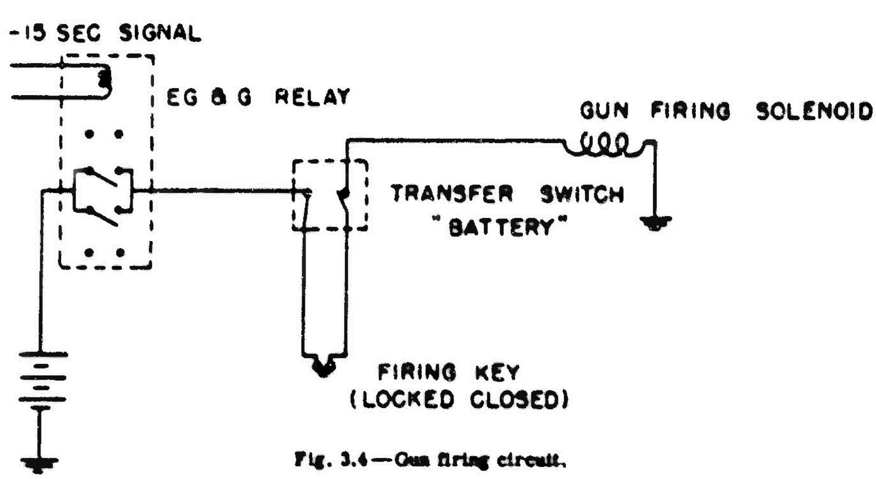

Fig. 3.4 — Gun firing circuit.

pertinent characteristics:

TNT and white-smoke compound, 4.09 lb
Projectile, MK 33
Projectile weight, loaded, 13.0 lb
Propellant for initial velocity of 2700 ft/sec
30-sec mechanical time fuze, M 502

3.3 BALLISTICS

The locations of the 10 gun bursts were to be at altitudes of 5000, 6000, 10,000, 11,000, 15,000, 15,000, 20,000, 21,000, 25,000, and 26,000 ft above the lagoon on a line defined by the intersection of the following planes:

1. A plane such that a horizontal line in that plane is perpendicular to the line from zero (Elugelab) to the photographic station on Rojoa. This plane makes an angle of 60° with the horizontal, passing through zero and leaning toward Rojoa.

2. A plane such that a horizontal line in that plane is parallel to the line from zero to the Rojoa photographic station. This plane makes an angle of 75° with the horizontal, passing through zero and leaning toward Bogallua.

The choice of this line implies that no gun is aimed toward the zero island, and, if the fuzing of a projectile be in error, the nearest possible horizontal approach to zero is 1000 ft.

It became apparent that the two bursts nearest Elugelab might possibly deposit fragments on Elugelab and Teiteiripucchi if the fragmentation pattern of the projectile had a pronounced radial cone. At shot time this would have been of little consequence since fragments would not reach the island prior to zero time. However, since test firing of the gun battery was necessary, it was imperative that no damage be sustained by island installations. Consequently, the two nearest bursts were moved to a higher altitude and a greater range from Elugelab. They were relocated at altitudes of 8000 and 9000 ft and at the same coordinates as the 10,000- and 11,000-ft bursts. The bursts, in elevation, are shown in Fig. 3.5.

The ballistic problem was computed for each gun prior to the operation. Train, elevation, and time of flight were calculated using standard range tables.[3] After the determination for standard conditions, the following corrections were applied (meteorological factors were estimated from average conditions at Eniwetok Atoll for October and November):

1. An initial velocity of 2700 ft/sec rather than the 2650 ft/sec (used in OP-1766). Erosion readings[4] for each gun indicated an approximate increase over the nominal 2700 ft/sec (new barrel) of 20 to 40 ft/sec. An assumed powder temperature of 70°F would reduce the initial velocity by about 20 ft/sec; further assuming a cold gun connection of 10 to 20 ft/sec, the resultant initial velocity is approximately 2700 ft/sec.

2. A decrease of 10 per cent in density due to a warm humid atmosphere. This appears reasonable when checked against calculated density changes and consequent range variation.[5]

3. A 10-knot rear wind. Climatic averages showed, for the time period under consideration, a surface wind of approximately 9 knots from ESE to ENE and upper winds of 12 to 18 knots from NE to SE. For an average of all 10 trajectories a value of a 10-knot rear wind seemed reasonable. The most accurate placement was necessary in the two lowest bursts (to prevent errors toward the zero island), and hence the surface wind was heavily weighted; in these cases a rear wind is from due east.

4. Drift was computed from OP-1766, and a trigonometric correction was applied to the angle of train.

Furthermore, assumptions as to the accuracy of gun laying (10 min in train, 2 min in elevation, and a fuze setting to within ±0.1 sec) indicated the calculations should be carried out to the nearest minute.

With the meager average climatic data it did not seem feasible to compute ballistic wind and density in detail. The main purpose of the preshot ballistic computations was to produce

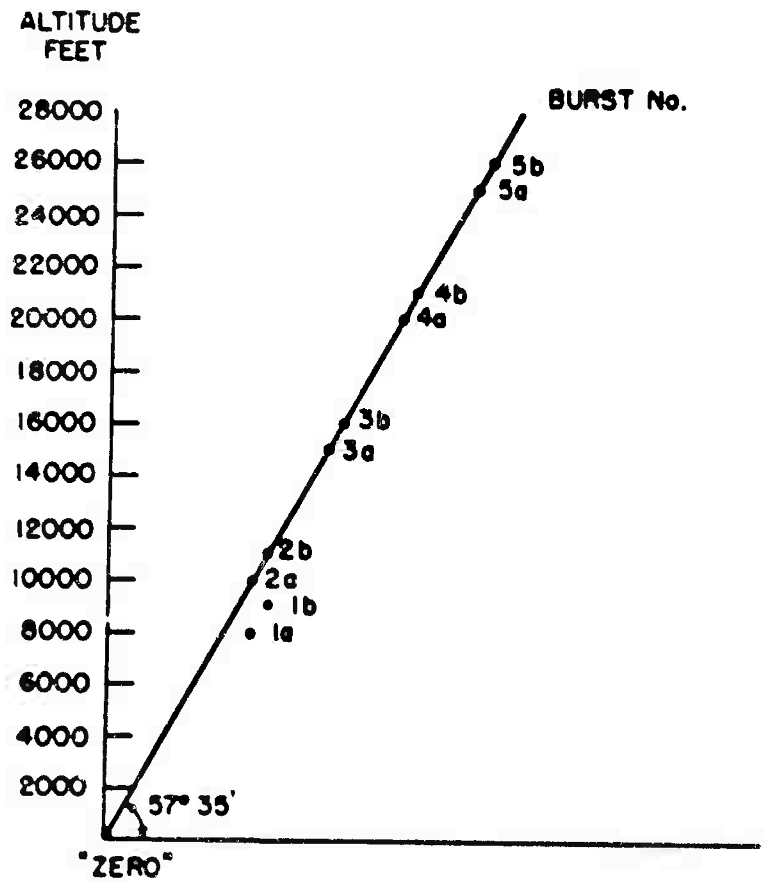

Fig. 3.6 — Location of gun bursts (elevation).

data for setting the guns to provide bursts as close to the designated points as possible.

To locate accurately the burst positions as they actually occurred, the ballistics were recomputed after the shot on the basis of meteorological conditions prevailing at shot time (see Appendix A). These calculations were vital since the ballistic data provided the only information on the burst positions; no triangulation cameras were available.

Again utilizing the standard AA Range Tables, with the known meteorological data, the actual burst positions were calculated. Ballistic wind and density were computed using reference 6. Changes in the preshot ballistic correction included temperature, wind, and density. The result of the postshot ballistic study showed that, in general, the bursts occurred 70 to 400 yd low, 100 to 250 yd short, and 15 to 40 yd to the right of their previously computed positions. The change in position for each burst was computed, and its true position in space was determined. In the process of film analysis the position of the burst was compared to its initially predicted position; the deviation is in good agreement with that derived from the ballistic computations.

Appendix B is an example of the ballistic study made for each burst.

REFERENCES

1. Ordnance Pamphlet No. 611 (OP-811), 3-inch Gun Mounts, Bureau of Ordnance, Navy Department.
2. P. B. Tweed, Shell, Fixed, Smoke, Colored, T49, 90 mm Gun M1A2, Picatinny Arsenal Report 1, Project TM1-1451A, November 1947.
3. OP-1766, AA Range Table for 3-inch, 50-caliber Gun.
4. OP-1692A, Range Table (Surface Targets) for 3-inch, 50-caliber Gun, p. 10.
5. OP-1692A, p 3.
6. NA-50-11OR-26, Instructions and Tables for Making Observations and Computing Ballistic Wind and Ballistic Density.

CHAPTER 4

CAMERA INSTALLATION

4.1 LOW-ALTITUDE SMOKE-PUFF CAMERAS

Motion-picture cameras were installed on Engebi, Rojon, Runit, and Parry to record the motion of the mortar smoke puffs. Mitchell and Bell & Howell 35-mm cameras were run at a speed of approximately 100 frames/sec. Lenses having various focal lengths were used, the choice being determined by the object distance of the camera and the expected maximum excursion of the smoke puff. Each camera was contained in a shielded box with an automatically opened lid upon which was mounted a plane mirror, thus directing the line of sight from the object down to the boxed camera. Table 4.1 summarizes the camera data for Mike and King mortar photography.

Table 4.1 — CAMERA DATA, MIKE AND KING MORTAR PHOTOGRAPHY

Camera station	Camera type	Lens focal length, mm	Object	Object distance, ft	Aiming Horizontal*	Aiming Vertical
			Mike Shot			
303 (Engebi)	Bell & Howell	75	620.01	16,100	19°34' R	0°
303 (Engebi)	Bell & Howell	75	620.02	14,900	23°23' R	0°
303 (Engebi)	Bell & Howell	75	620.03	12,900	28°55' R	0°
303 (Engebi)	Bell & Howell	75	620.04	12,400	40°16' R	0°
306 (Rojon)	Mitchell	152	† 621.01	44,800	16°47' L	0°
306 (Rojon)			† 621.02	34,900		
306 (Rojon)	Mitchell	152	621.03	26,800	23°40' L	0°
306 (Rojon)	Mitchell	152	621.04	23,200	27°38' L	0°
307 (Runit)	Mitchell	152	621.05	41,100	41°39' L	0°
307 (Runit)	Mitchell	152	621.06	13,100	55°15' L	0°
308 (Parry)	Mitchell	75	622	750		22°00'

Table 4.1 — (Continued)

Camera station	Camera type	Lens focal length, mm	Object	Object distance, ft	Aiming	
					Horizontal*	Vertical
			King Shot			
306 (Rojoa)	Mitchell	152	621.10	18,900	12°00′ R	0°
306 (Rojoa)	Mitchell	152	621.11	18,500	14°30′ R	0°
306 (Rojoa)	Mitchell	152	621.12	18,400	17°20′ R	0°
306 (Rojoa)	Mitchell	152	621.13	18,300	20°10′ R	0°
306 (Rojoa)	Mitchell	152	621.14	17,900	29°20′ R	0°
306 (Rojoa)	Bell & Howell	152	621.15	18,650	44°37′ R	0°
308 (Parry)	Mitchell	75	622	750		

*R = right of ground zero; L = left of ground zero.
†Same camera; two bursts on one film.

4.2 HIGH-ALTITUDE GUN-BURST CAMERAS

Mitchell 35-mm cameras with 152-mm lenses, operating at a nominal 100 frames/sec, were installed at Station 306 on Rojoa for the purpose of photographing the gun bursts. The method of installation was identical with that for the mortar photography. Table 4.2 summarizes the gun camera data.

Table 4.2 — CAMERA DATA, MIKE GUN-BURST PHOTOGRAPHY

Camera station	Camera type	Lens focal length, mm	Object	Object distance, ft	Aiming	
					Horizontal*	Vertical
306 (Rojoa)	Mitchell	100	1a–b	49,000	3°48′ L	11°30′
306 (Rojoa)	Mitchell	152	2a–b	48,500	3°48′ L	13°48′
306 (Rojoa)	Mitchell	152	3a–b	48,300	5°38′ L	20°09′
306 (Rojoa)	Mitchell	152	4a–b	45,700	7°48′ L	26°51′
306 (Rojoa)	Bell & Howell	152	5a–b	46,000	10°20′ L	33°42′

*L = left of ground zero.

CHAPTER 5

DATA ANALYSIS

5.1 LOW-ALTITUDE BURSTS

Upon receipt of the film prints the normal procedure of plotting the smoke-puff edges, frame by frame, was employed.[1,2] The resultant series of contours were then measured to obtain the displacement of the object as a function of frame number. The measured displacement was corrected for magnification of the Recordak (the projection instrument by means of which the contour plot was traced). The resultant displacement on the film was then translated to true displacement in three-dimensional space. For the geometry used in this experiment, it can be shown that the true displacement in space, y_{feet}, is related to the measured film displacement, x_{mm}, by

$$y = \frac{x R \sin \phi \cos \beta \left[1 + \frac{\cos (\beta + \phi) \sin \beta}{\sin \theta}\right]}{\sin (\alpha + \beta + \phi) \left[f \sin \theta + x \cos \beta \cos (\beta + \theta)\right]}$$

where R = range (ft) from camera to weapon zero

ϕ = angle between line from weapon zero to camera and line from weapon zero to smoke puff

α = angle between line from camera to weapon zero and line from camera to smoke puff

β = angle between optic axis and line from camera to smoke puff

θ = angle between line of motion of smoke puff and line from smoke puff to camera

f = lens focal length (mm)

Knowledge of the camera speed (available from timing marks on the film), together with the true spatial displacement, allows one to plot displacement vs time.

Previously used methods of data analysis[1] were not employed; a preliminary reduction of data by the displacement-time tangent technique produced anomalous results indicating extremely high pressures at long ranges. It is believed that these results were due to optical refraction phenomena; on previous operations refraction effects had been shown to be below the camera resolution limits. However, the magnitude of the Ivy detonations with the instrumentation at higher pressure levels than before, together with the greatly increased shock radii involved, seriously affected the determination of the particle displacement while the optical path passed through the strong shock region.

The following method was utilized in the reduction of the film data. From the measured time of shock arrival at each instrument station, distance from zero was plotted as a function of time on logarithmic paper. From the measured displacement of the smoke puff as a function of time, the particle position lines (world lines) were drawn. Slopes a (of the time of arrival

curve) and m (of the world lines) at each station range were measured directly from the plotted data points. Without recourse to the Rankine-Hugoniot relations the peak shock velocity and peak material velocity were computed from

$$U = \frac{sR}{t}$$

$$u = \frac{mR}{t}$$

By conservation of momentum alone the peak overpressure may be determined

$$P_s = \rho_0 U u$$

Aside from eliminating effects due to refraction, the above method is ideally suited to the determination of the hydrodynamic yield by the analytic solution.[3,4] The measurements of radius R, time t, slopes s and m, and the rate of change of slope m, (d ln m)/(d ln t), remove the analytic solution from serious dependence upon the equation of state. The foregoing data from Mike have been used in the analytic solution and result in an average yield of 10.1 Mt over a pressure range of from 13 to 2 atm. This is lower than the hydrodynamic yield of 10.4 Mt obtained from the analytic solution in the fireball region; a lower yield is expected at long distances and low altitudes because of atmospheric inhomogeneity. The apparent yield derived from the high-altitude gun bursts is correspondingly higher than the hydrodynamic fireball yield. The extension of the solution beyond the fireball region and down to such low pressures is extremely valuable in broadening the pressure range over which the analytic solution is valid.

The position of the burst was measured on the film with reference to the known camera object axis; in this manner the altitude of the burst may be determined as well as its deviation from station coordinates in the horizontal plane. From these measurements the true slant range from zero was determined.

Figure 5.1 is an enlarged 35-mm frame of three of the reef stations at Mike zero time. The mortar bursts, rather indistinct on the enlargement, appear at the left edge (to the left of the lightning stroke), in the right edge of an overexposed area (due to reflection from the camera mirror), and over the right-hand gun silhouette. Figure 5.2 shows the same stations during the passage of the shock wave. The left station has been engulfed by the fireball and dust cloud, the center station puff has been placed in motion by the shock wave, and the third station has not yet been displaced. Of passing interest on this frame are the outline of the shock wave against the background clouds (in the right third of the photograph) and the spray rising behind the shock front (light area on the horizon).

5.2 HIGH-ALTITUDE BURSTS

The procedure is similar to that employed in the analysis of the low-altitude mortar bursts. However, the determination of the relation between measured displacement on the film and the true displacement in space is much more complex. A simplification of the rigorous solution of the three-dimensional geometry, applicable to the determination of displacement at an early time corresponding to the time of peak pressure, results in

$$D = \frac{Rd}{f}\left[\frac{\sin^2 \epsilon \cos^2 \mu}{\sin^2 (\alpha + \phi)} + \frac{\cos^2 \epsilon \sin^2 \phi}{\sin^2 (\mu + \phi)}\right]^{1/2}$$

where D = true spatial displacement (ft)
d = measured film displacement (mm)

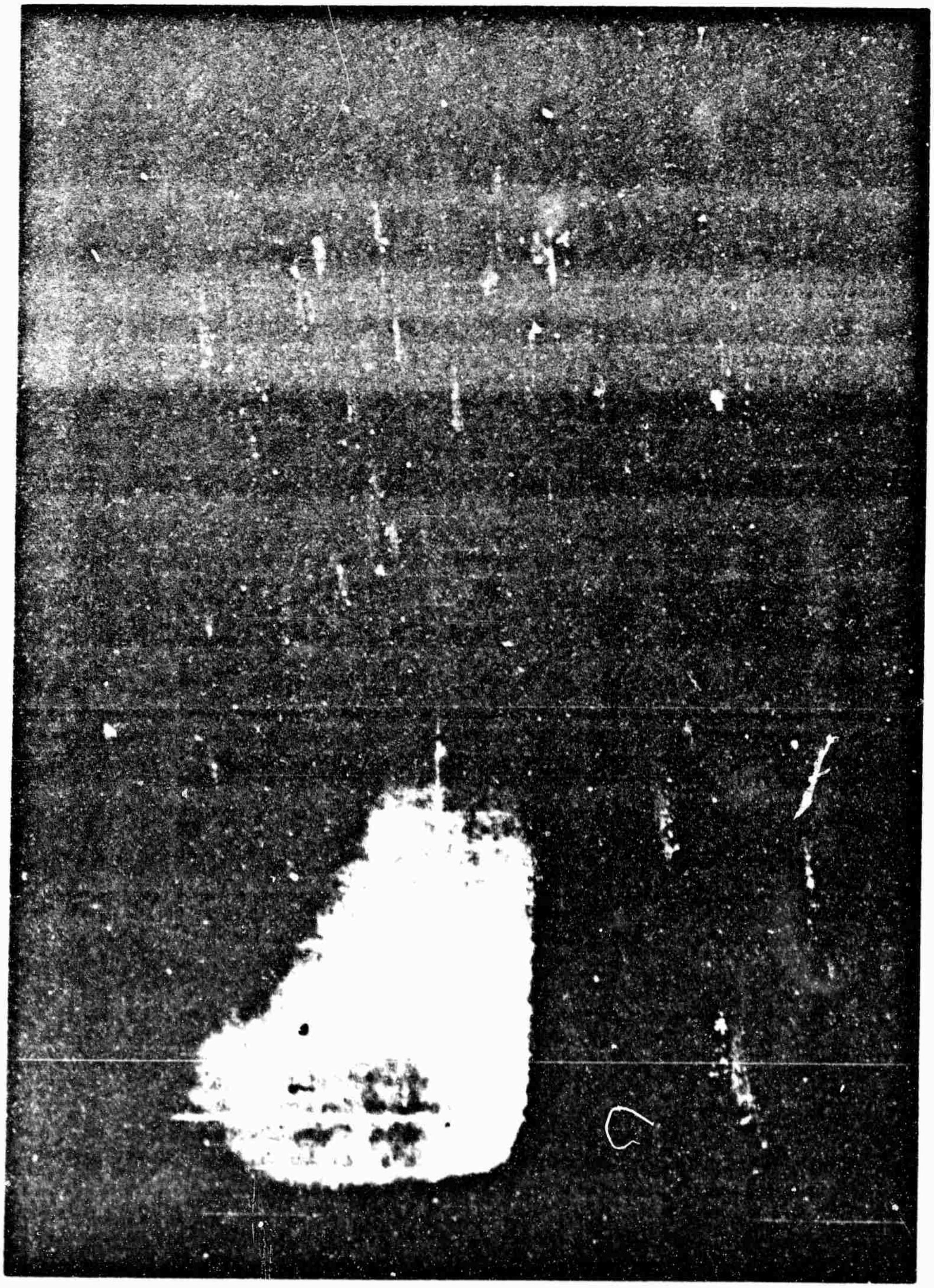

Fig. 5.1—Reef stations at zero time.

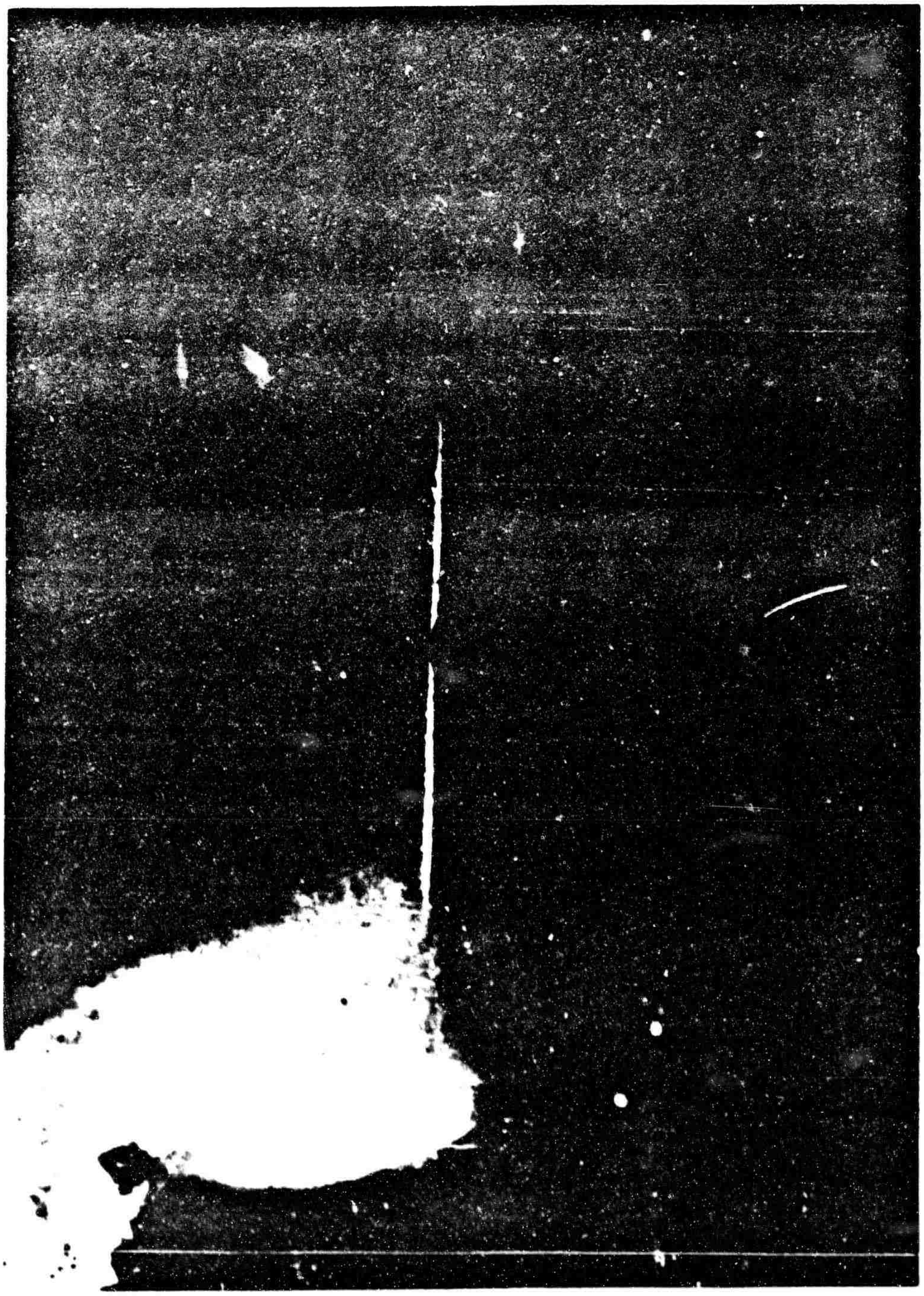

Fig. 5.2 — Reef stations during shock passage.

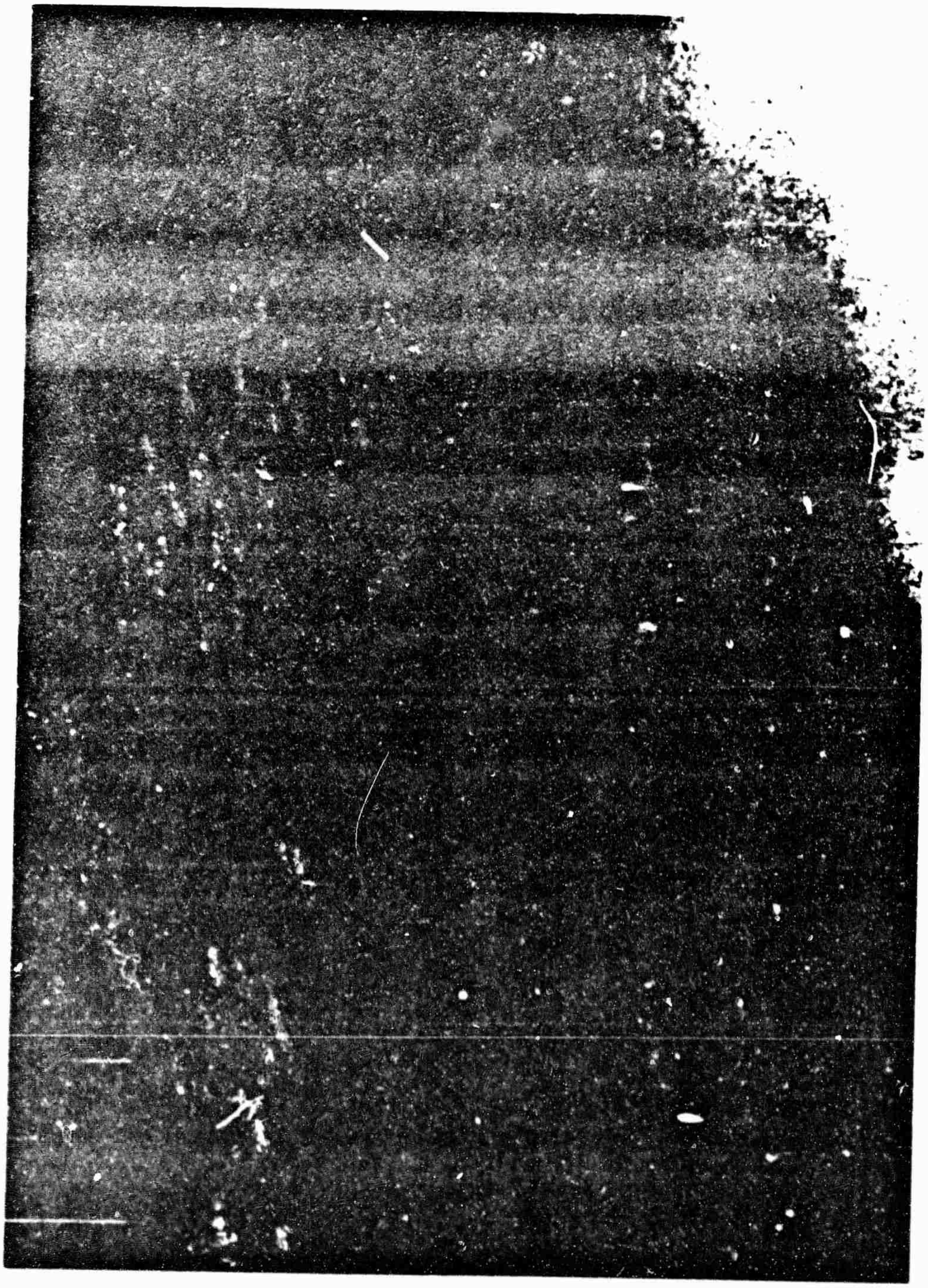

Fig. 5.3—Gun bursts at 15,000-ft altitude.

R = distance from camera to initial position of gun burst
f = lens focal length (mm)
ϵ = angle between horizontal displacement and actual displacement on film
μ = vertical angle between horizontal and line from camera to burst
ϕ = horizontal angle between line from weapon zero to camera and line from weapon zero to gun burst ground zero

$$\phi = \tan^{-1}\left[\frac{\tan \xi}{\cos (\alpha + \phi)}\right]$$

ξ = vertical angle between horizontal and line from weapon zero to gun burst
α = horizontal camera aiming angle

Figure 5.3 is an illustration of the gun-burst photography. The diffuse objects are gun bursts at an altitude of 15,000 ft and at a distance of 7.5 miles from the camera. The more distinct objects bracketing the bursts are the remains of parachutes used by Project 6.11 to place pressure instruments for free-air recording.

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1. D. F. Seacord, Jr., Blast Measurements, Part III, Blast-wave Material-velocity Measurements, Buster-Jangle Project 10.10 Report, WT-415, March 1952.
2. D. F. Seacord, Jr., Blast Measurements, Part I, Blast-wave Material-velocity Measurements, Tumbler-Snapper Projects 19.2a-f Report, WT-556, August 1952.
3. F. B. Porzel, Procedure for Analytic Solution on Fireball Growth, Los Alamos Scientific Laboratory Report J-16455 (not available).
4. F. B. Porzel, Los Alamos Scientific Laboratory Report LA-1406 (in preparation).

CHAPTER 6

RESULTS

6.1 MIKE SHOT

The instrumentation functioned in a satisfactory manner. The four reef mortars (Stations 620.01 to 620.04) all fired and produced smoke puffs; four of the six raft mortars (Stations 621.01 to 621.04) fired, and puffs were observed; one raft mortar (Station 621.05) and the mortar on Parry (Station 622) failed to receive their radio firing signal; one raft mortar fired, but no puff was observed on the film (Station 621.06), probably because of a faulty mortar charge or camera misalignment; all 10 guns fired.

The data derivable from the films do not follow the percentage success in instrument functioning; this is primarily due to the fact that dust and smoke produced by the thermal radiation obscured the camera field of view before the shock wave reached the smoke puff. This occurred on the film covering reef Station 620.04. The complete motion of the puffs could not be followed, even at the camera station on Rojoa, because of the dust obscuration. Data from Station 620.01 were lost since the puff was engulfed by the fireball before any shock-induced motion could be discerned.

Two of the gun bursts (3 and 5a) started their motion slightly outside the camera field of view; consequently peak material velocity and overpressure could not be determined for these two points.

Of the proposed instrumentation, 70 per cent of the stations produced data. Since the gun bursts were in pairs separated by 1000 ft, the lack of data from one-half of each of two pairs was not serious for defining a pressure-distance curve, and the data are considered as 75 per cent of planned. The high-altitude portion of the project was considered as a gamble from the beginning since cloud cover could easily prevent the photography of the bursts; that any data were obtained may be considered as luck.

Table 6.1 presents station range, time of shock arrival, peak shock velocity, peak material velocity, and peak overpressure for Mike shot. Figures 6.1 to 6.4 are graphs of these data; for comparison, Fig. 6.4 contains the theoretical pressure-distance curve (reflection factor of two)[1] for a 10-Mt surface burst.

6.2 KING SHOT

Five of the six raft mortars fired, and four of the five produced bursts (again indicative of one faulty charge). Of the four bursts initially visible, one (Station 621.13) was obscured by thermal dust prior to motion. The mortar on Parry (Station 622) was fired by hand; however, a power failure shortly after zero time prevented the camera from running. Instrument operation was, consequently, 71 per cent, but only 43 per cent of the data was obtained.

Table 8.1 — RESULTS, MIKE SHOT

Station	Slant range, ft	Time of arrival, sec	Peak shock velocity, ft/sec	Peak material velocity, ft/sec	Peak overpressure, psi
620.02	5,935	0.63	4190	3155	204.8
620.03	8,310	1.34	2910	1800	81.1
621.01	16,000	5.08	1700	650	17.0
621.02	21,500	8.33	1500	440	10.2
621.03	30,130	15.45	1270	245	4.8
621.04	37,200	20.06	1250	195	3.6
Gun burst					
1a	10,160	1.78	2600	1720	56.0
1b	11,300	2.34	2320	1520	42.9
2a	11,690	2.44	2210	1450	37.9
2b	12,720	2.89	2070	1350	32.2
3b	18,580	6.02	1620	1040	16.5
4a	23,000	9.17	1430	906	11.1
4b	24,100	9.92	1400	890	10.3
5b	29,780	12.14	1470	930	9.8

Table 8.2 presents range, time of arrival, peak shock velocity, peak material velocity, and peak overpressure. These data are plotted with the Mike data in Figs. 8.1 to 8.4; for comparison, the theoretical pressure-distance curve for a 550-Kt burst (reflection factor of two) is included in Fig. 8.4.

Table 8.2 — RESULTS, KING SHOT

Station	Slant range, ft	Time of arrival, sec	Peak shock velocity, ft/sec	Peak material velocity, ft/sec	Peak overpressure, psi
621.10	3640	0.99	2390	1560	57.1
621.11	4590	1.40	2090	1190	38.3
621.12	5580	1.93	1805	880	24.5

8.3 DISCUSSION AND INTERPRETATION OF RESULTS

The Mike low-altitude data points are in good agreement with the theoretical curve for 10 Mt over an ideal surface (reflection factor of two) at high pressures. At long ranges the measured pressures are lower than the ideal curve because of atmospheric acoustic refraction focusing the shock wave upward.

The high-altitude data show a departure from the low-altitude curve and indicate pressures higher than for a homogeneous medium. A preliminary study of the effects of an increasingly rarified atmosphere on the propagation of a shock wave has shown that the pressures should be higher at high altitudes than they are near the surface. Assuming that the absolute pressure behind the shock is everywhere constant at a given time, the shock velocity increases as the ambient pressure decreases with altitude. A higher shock velocity and an earlier time of arrival are indicated by the data. The increased shock velocity, together with

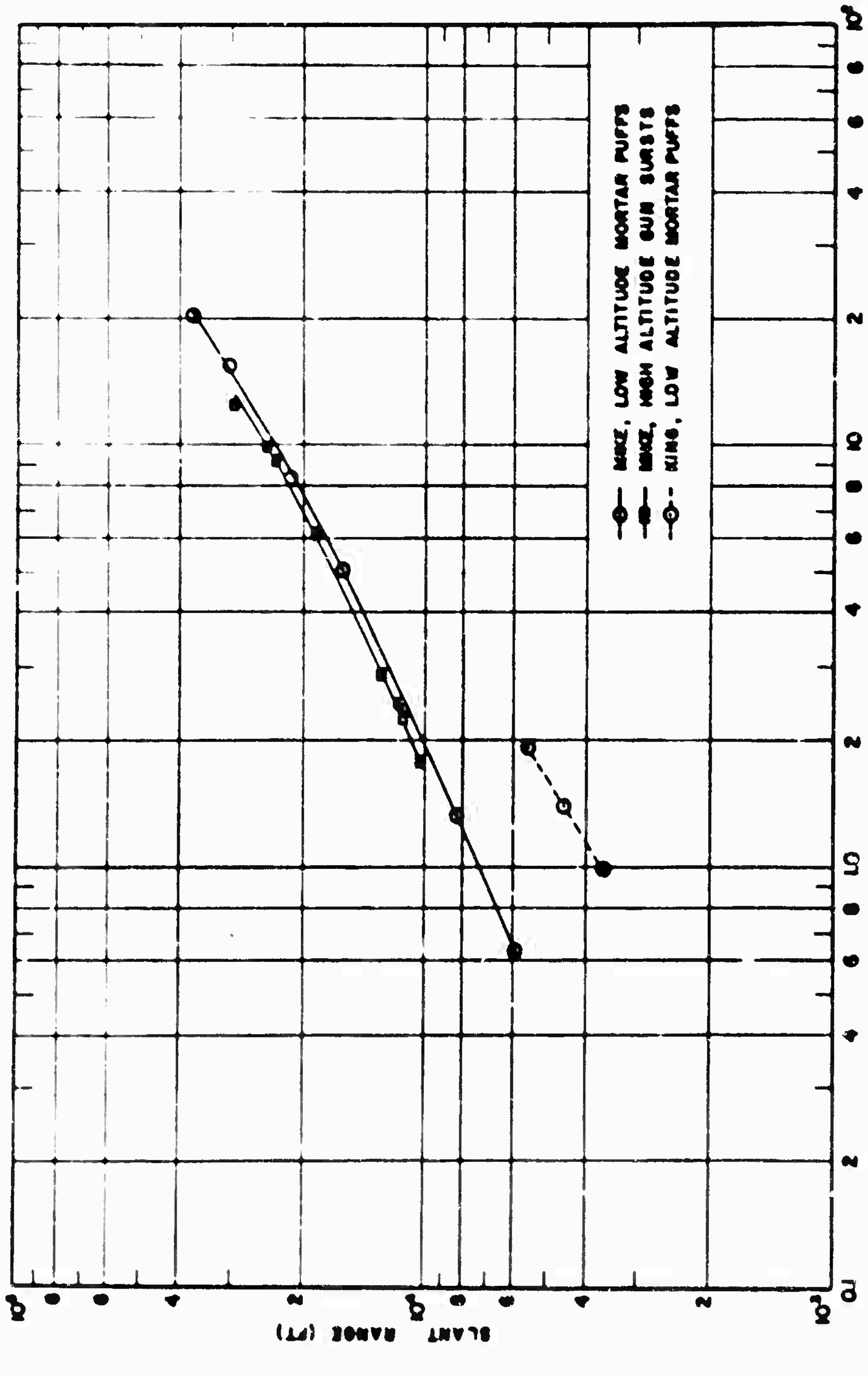

Fig. 8.1—Time of arrival.

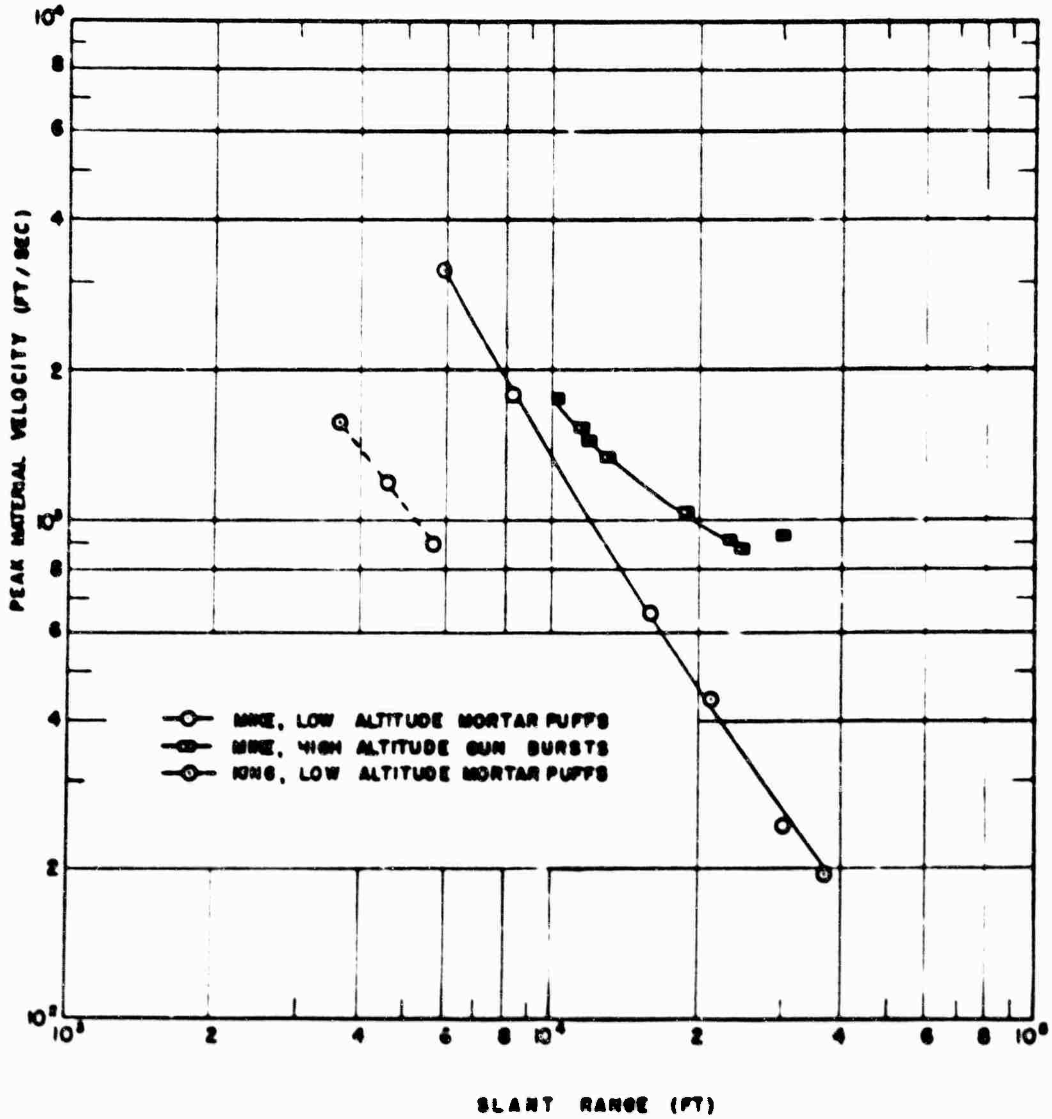

Fig. 6.2—Peak material velocity.

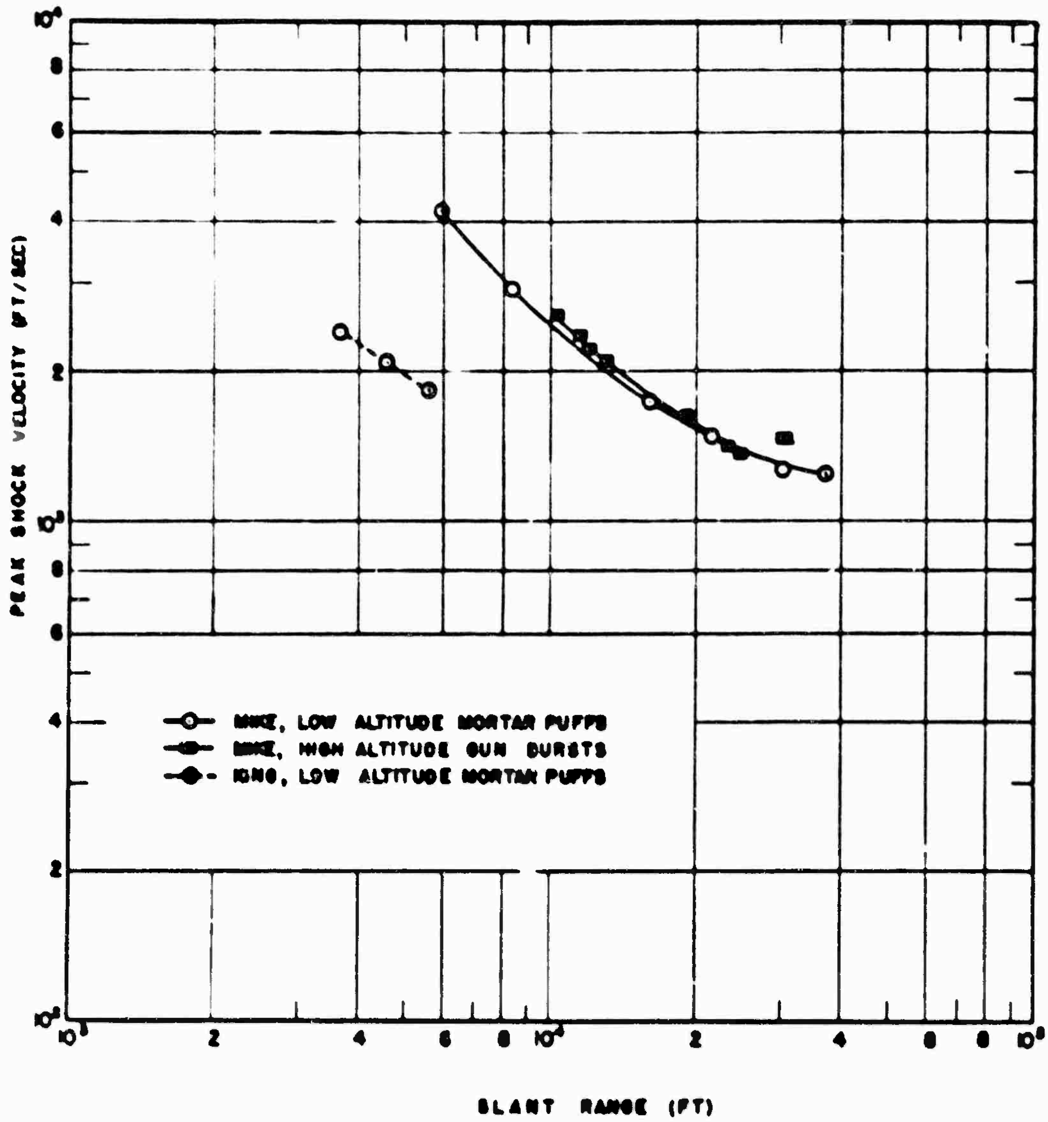

Fig. 6.3—Peak shock velocity.

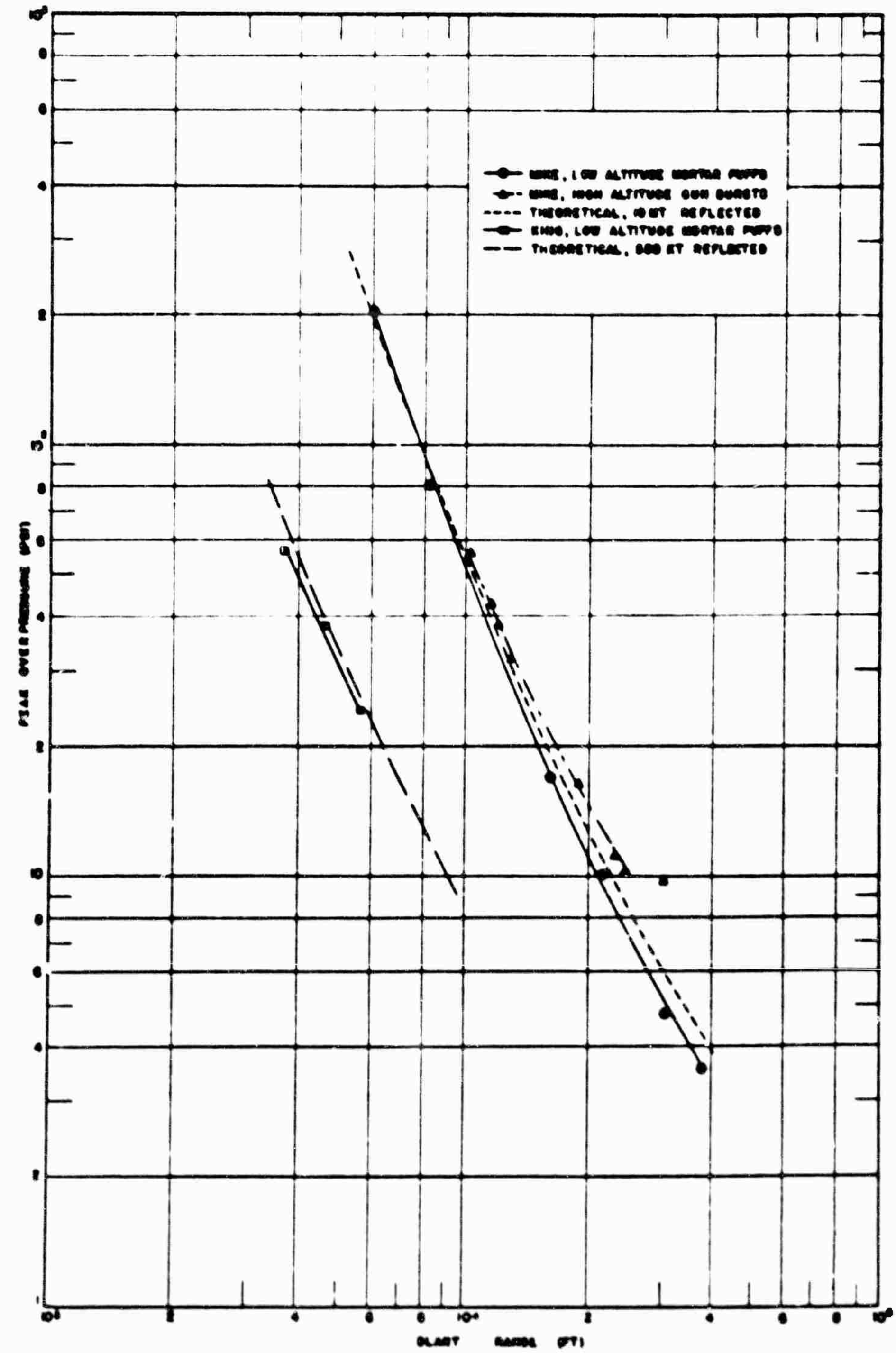

Fig. 6.4—Peak overpressure.

a higher materiel velocity, results in an increase in overpressure at the high altitudes. Furthermore, since the increased shock velocity in the rarified medium produces an asymmetry in the shock front, when comparing pressures at the surface with those at high altitudes at the same slant range, it follows that the surface pressure will be lower in relation to the high-altitude pressure because of pressure decay with distance. That the Fuchs correction[2] is not applicable in this case is evident from the pressure levels involved.

The data derived from the highest gun burst are under suspicion; the anomalous behavior may be due to an "atmospheric discontinuity" which may have existed at an altitude of approximately 10,000 ft. At this level the temperature decreased at a greater rate; the wind had shifted in direction and increased in velocity. This characteristically different air mass overriding the lower level air mass may well have acted as a reflecting boundary. Gun burst 5b, above this level, exhibits high shock and material velocities and high peak overpressures.

The three King data points lie slightly below a theoretical 550-Kt curve (reflection factor of two); all King points are in the Mach region.

It should be noted that the velocities and peak overpressures have not been corrected for ambient wind conditions but are the values as actually measured. If the data were corrected for wind, the three King values would be lowered 1 per cent and pressure at the two closest Mike stations increased by 0.5 per cent. With a value of ±10 per cent applied to the pressure data, these minor corrections are not of importance.

6.4 PRECISION OF MEASUREMENTS AND METHOD ERRORS

A discussion of the errors inherent in this method of pressure measurement may be found in reference 3. The error in camera speed is approximately ±2 per cent over the region of measurement resulting in a precision index of ±0.02 sec in time. The measurement of slopes n (time-of-arrival curve) and m (world line) was repeated several times; the relative error in n is approximately ±2 per cent and in m, ±3 per cent. The ranges of the mortar puffs and gun bursts are known, on the average, to within 1 per cent. The meteorological data utilized in the experiment were obtained some hours prior to shot time; however, because of the rather stable atmospheric conditions at the shot site, a reasonable relative error in density of ±1 per cent has been assigned. Propagation of the relative errors results in a maximum value of ±8 per cent at the closest stations, decreasing to ±6 per cent at the most distant stations, as the relative error in the derived pressure; the range error decreases from ±1 per cent to ±0.5 per cent.

REFERENCES

1. F. B. Porzel, Los Alamos Scientific Laboratory Report LA-1406 (in preparation).
2. Karl Fuchs, The Effect of Altitude, Los Alamos Scientific Laboratory Report LA-1021, Vol. VII, Part II, Chapter 9.
3. D. F. Seacord, Jr., Blast Measurements, Part I, Blast-wave Material-velocity Measurements, Tumbler-Snapper Projects 19.2a-f Report, WT-556, August 1952.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 BLAST HYDRODYNAMICS

The data obtained on Mike and King confirm the theoretical pressure-[illegible] and time-of-arrival curves of Report LA-1406. The effects of atmospheric inhom[illegible]y were found to be significant at slant distances greater than 10,000 ft.

Requirements for the mass-motion experiment on future tests are somewhat as follows:

1. There is apparently little requirement for measurement of peak pressure or time of arrival at distances less than 10,000 ft for the sole purpose of establishing the free-air pressure-distance curve.

2. There is a requirement to measure peak pressure at both low and high altitudes (slant ranges and altitudes well in excess of 10,000 ft) in order to improve the quantitative understanding of the effect of atmospheric inhomogeneity.

3. A further requirement exists since the technique is directly applicable to the analytic solution for determination of the total hydrodynamic yield. The measurements should extend from fireball breakaway down to pressures of several atmospheres or, for air bursts, to at least cover the free-air region. The emphasis here would be on the hydrodynamics deep in the interior of the shock wave, for which the method is well adapted; furthermore, the details near the shock front are fairly well understood.

7.2 THERMAL DUST AND CAMERA LOCATION

The cameras were installed at a central location atop the timing stations on Engebi, Rojoa, and Runit. This choice of location was excellent for operational facility but was unfortunate from the point of view of object obscuration. The area of dirt and vegetation between the camera and the lagoon beach was severely scorched on Engebi and Rojoa, resulting in a pall of smoke and dust which arose and clouded the field of view, in many cases before the desired data on mass motion were obtained. Future photography of this nature (on large weapons tests) should bear in mind the thermal effects; cameras should be placed as close to the edge of the water as is feasible and upwind of any smoke-producing material.

7.3 PHOTOGRAPHIC METHOD

The photographic problems associated with this experiment were resolved on Buster-J[illegible]le and were successfully applied on Tumbler-Snapper and on Ivy. Decisions on type of [illegible]a, film speed, and lens focal length were made in consultation with EG&G personnel; all [illegible]graphic work was conducted by that organization.

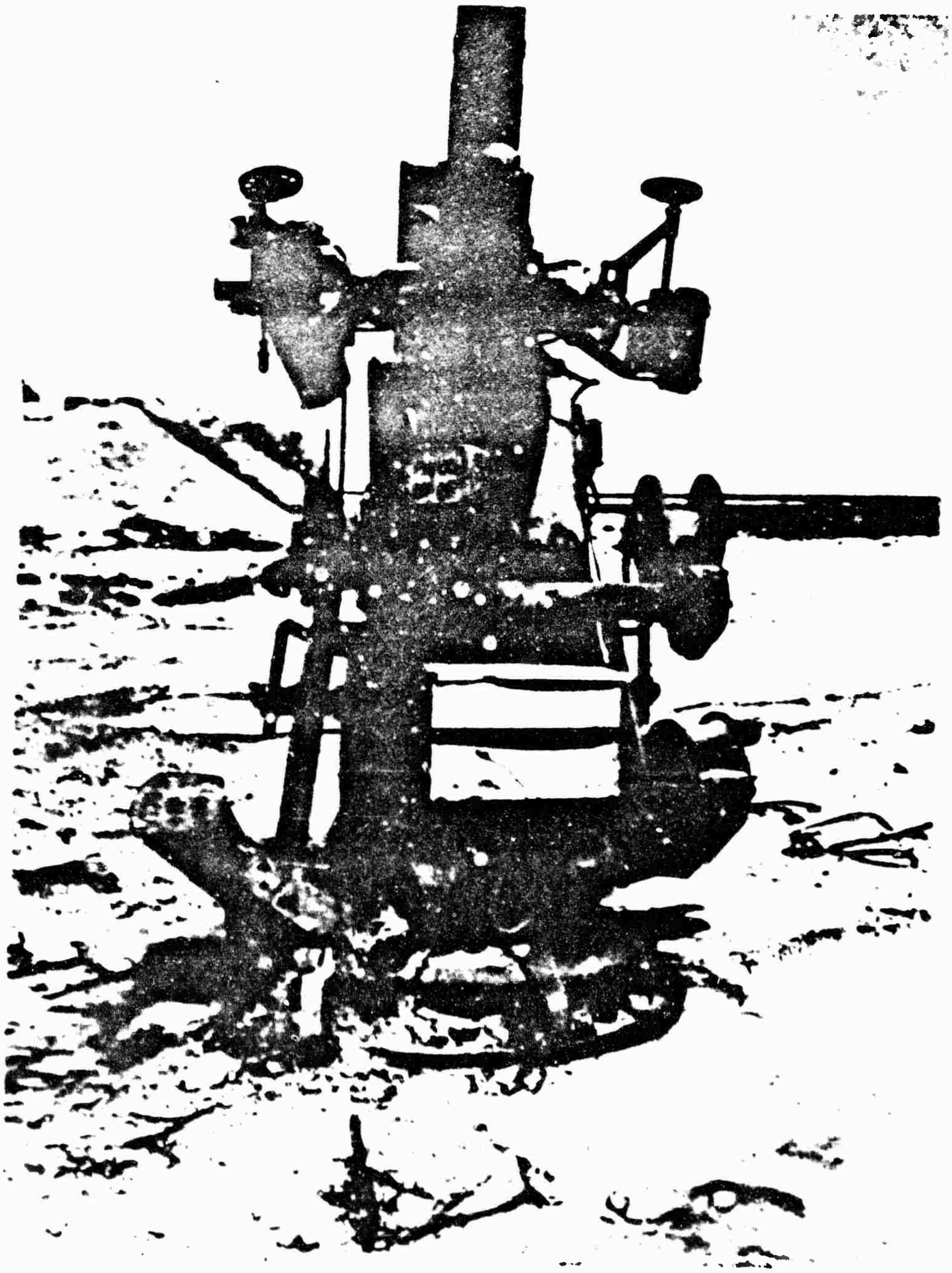

Fig. 7.1—Damage to Station 623.10 (front view).

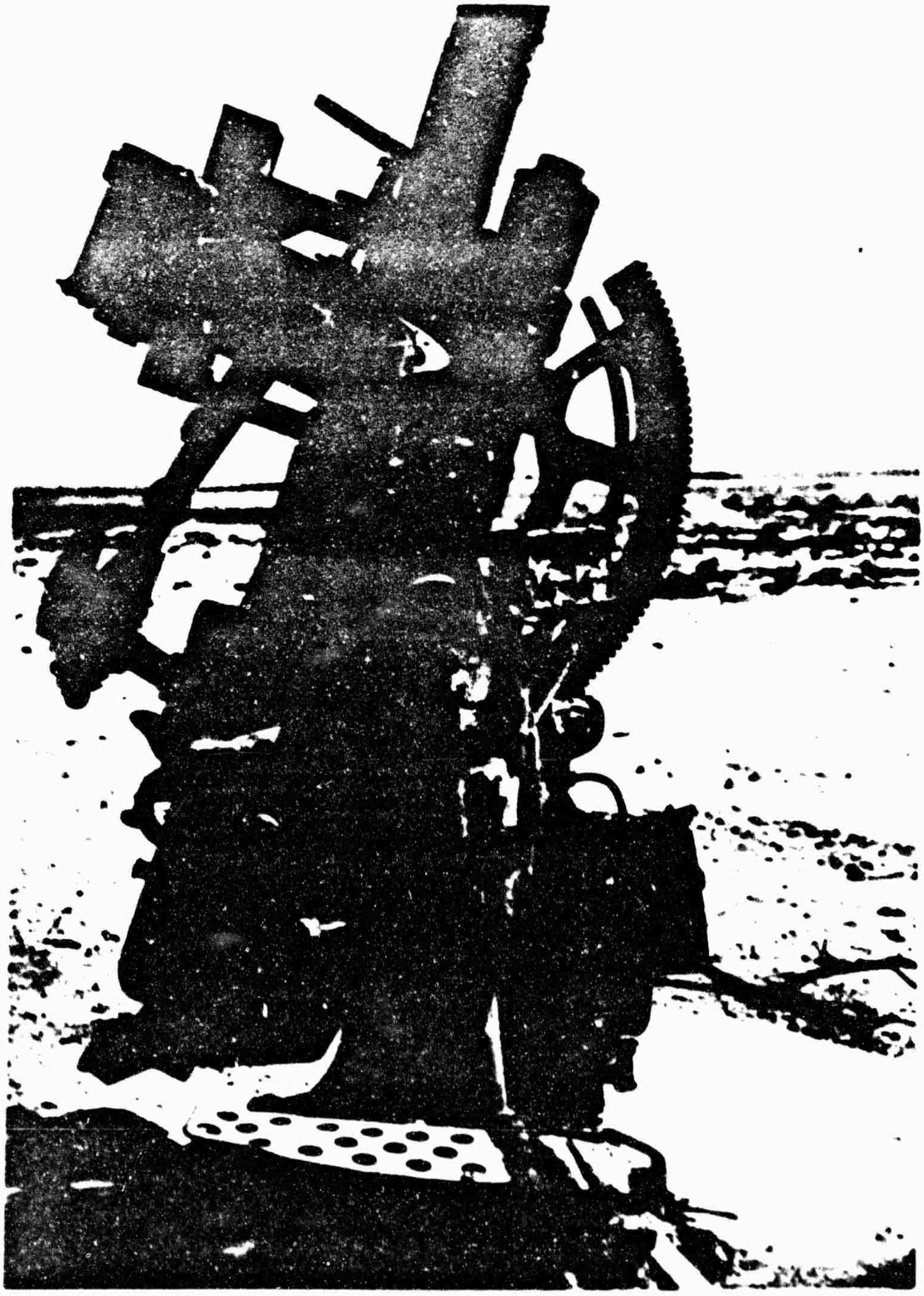

Fig. 7.2—Damage to Station 623.10 (side view).

7.4 LOGISTIC SUPPORT

The installation of the guns on Engebi was the biggest problem encountered by the project. The fine coordination of activities rendered by Group J-6, LASL, the outstanding performance of the Navy gun crew, and the equipment and skilled personnel supplied by H&N all contributed to completing the installation with a minimum of difficulty.

The placement of the rafts and mortar equipment proceeded smoothly. By participating to the fullest extent in the full-scale dry run, many minor problems were overcome. The actual mooring of the raft stations began at 0600, M-1 day. By 1330 all rafts had been moored and activated, and the guns on Engebi had been loaded and prepared for firing.

7.5 DAMAGE SUSTAINED BY GUNS

A brief description of the damage sustained by the gun battery on Engebi (6400 yd from Mike zero) may be of interest.

Little physical damage occurred with the exception of one mount (Station 623.10). Figures 7.1 and 7.2 show the damage to this station. The trainer's hand wheel, telescope bracket, bucket seat, and foot pedals were apparently struck by a large piece of concrete, pieces of which may be seen in Fig. 7.1. The greatest damage was inflicted by local atmospheric conditions rather than by the effects attendant upon the nuclear detonation. By the time the radiation had decayed to a level which would have permitted personnel to work on the guns, rust and corrosion had set in and rendered the equipment useless and beyond the repair facilities available in the field at the time.

APPENDIX A

METEOROLOGICAL DATA

The basic meteorological data for Mike and King shots were provided by Joint Task Force 132 (JTF-132) Weather Central and are reproduced in Tables A.1 and A.2.

From these data, ambient density at low altitudes (~300 ft, the mortar burst region) was computed to be 1.15 g/liter. Similarly, for King, ambient density was 1.14 g/liter.

For the high-altitude gun bursts on Mike, data on ambient pressure, temperature, and dew point were plotted as a function of altitude and interpolated at the gun-burst altitudes. Figure A.1 gives the ambient pressure, Fig. A.2 the temperature, Fig. A.3 the dew point, and Fig. A.4 the wind velocity and direction. An atmospheric discontinuity will be noted at about 20,000 ft; the temperature drops at a greater rate while the wind shifts in direction and increases in velocity. Table A.3 gives the ambient pressure and computed ambient density at the altitudes of the gun bursts.

Table A.1 — METEOROLOGICAL DATA, MIKE SHOT
USS Estes
Eniwetok, Marshall Islands
0100 Local (1300 Z), 1 November 1952

	Wind					
Altitude, ft	Direction, degrees	Speed, knots	Pressure, mb	Temp., °C	Dew point, °C	Altitude,* ft
Surface	110	12	1000	25.6	23.6	280
1,000	110	13				
2,000	110	15				
3,000	110	15				
4,000	120	15				
5,000	120	13	850	18.8	17.2	4,930
6,000	130	14				
7,000	130	16				
8,000	130	17	733	11.8	10.2	
9,000	130	17				
10,000	130	14	700	9.5	7.2	10,330
12,000	130	08				
14,000	140	09				
16,000	150	10	633	6.5	1.8	
18,000	160	11				
20,000	160	10	500	6.2	−6.8	19,270
25,000	250	17	445	−11.2	−26.8	
			400	−16.7	M	24,890
30,000	240	24	358	−24.0		
			300	−29.7	M	31,780
35,000	240	14				
40,000	250	15	200	−48.5	M	40,910
45,000	330	16	150	−61.2	M	46,960
50,000	350	16	117	−71.0	M	
55,000	040	08				
60,000	070	34				
65,000	070	36				
70,000	080	20				
75,000	100	19				
80,000	080	17				
85,000	100	08				
90,000	090	04				

*Altitude at prescribed pressure levels.

Table A.2—METEOROLOGICAL DATA, KING SHOT
Eniwetok, Marshall Islands
0900 Local, 16 November 1952; 2100 Z, 15 November 1952

Altitude, ft	Wind Direction, degrees	Wind Speed, knots	Pressure, mb	Temp., °C	Dew point, °C	Altitude,* ft
Surface	070	17	1010	28.3	23.5	
1,000	070	20	1000	26.5	26.2	310
1,500	070	31				
2,000	060	22	933	23.5	21.8	
3,000	090	25				
4,000	090	26				
5,000	090	25	850	20.8	10.8	5,000
6,000	090	25				
7,000	090	24	796	16.5	12.6	
8,000	100	21				
9,000	090	20				
10,000	070	20	700	11.6	3.2	10,420
12,000	070	18				
14,000	060	16	623	4.6	−14.8	
16,000	[illegible]	14				
18,000	080	19	500	−4.2	M	19,370
20,000	080	30				
25,000	050	26	400	−15.5	M	25,020
30,000	030	08	300	−30.5	M	31,960
35,000	340	29				
40,000	330	41	200	−50.8	M	41,010
45,000	340	38	150	−65.0	M	46,970
50,000	120	07				
55,000	060	06	100	−79.2	M	54,790
60,000	060	22	93	−81.0	M	
65,000	070	23	66	−77.0	M	
70,000	020	07	50	−58.0	M	68,030
75,000	240	14				
80,000	240	11				
85,000	230	13				

*Altitude at prescribed pressure levels.

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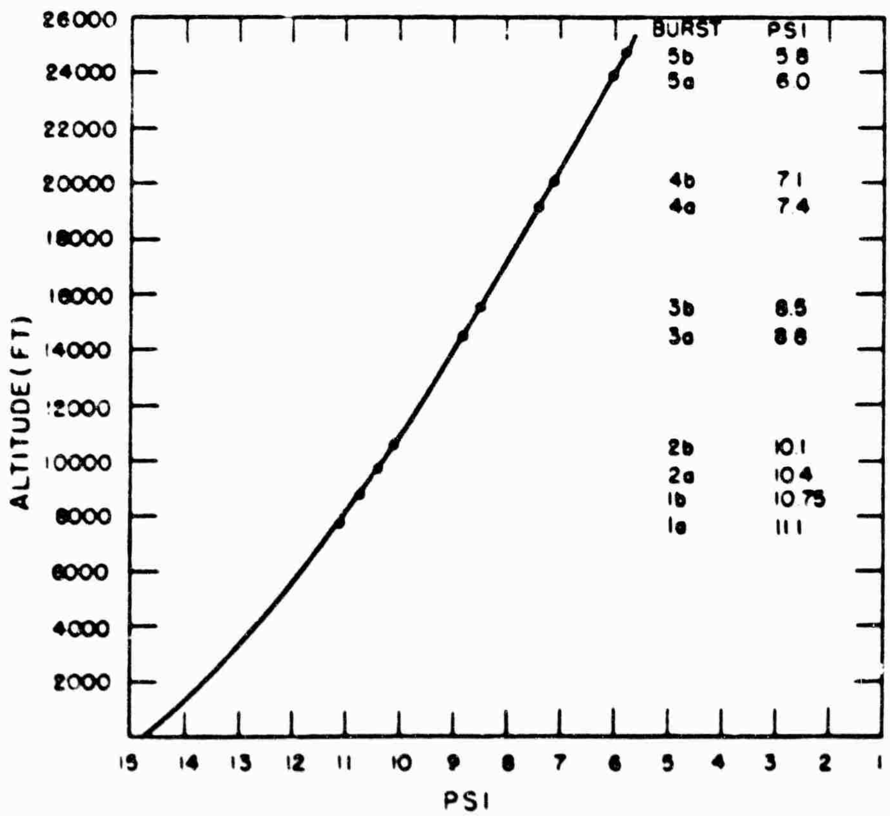

Fig. A.1 — Ambient pressure vs altitude.

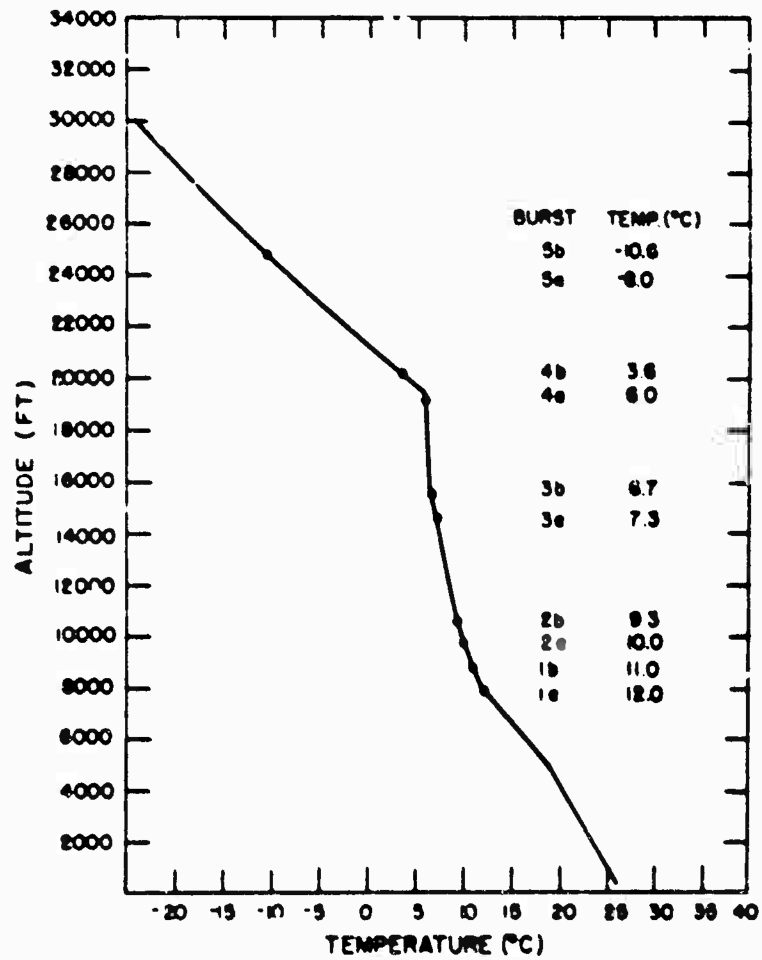

Fig. A.3 — Ambient temperature vs altitude.

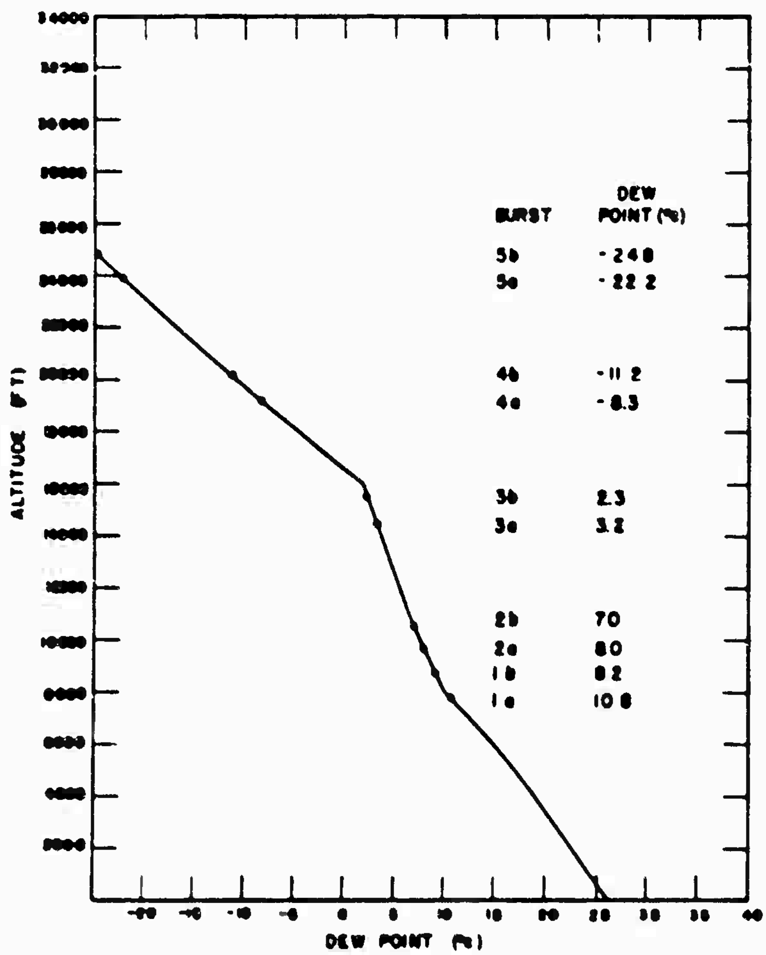

Fig. A.3—Dew point vs altitude.

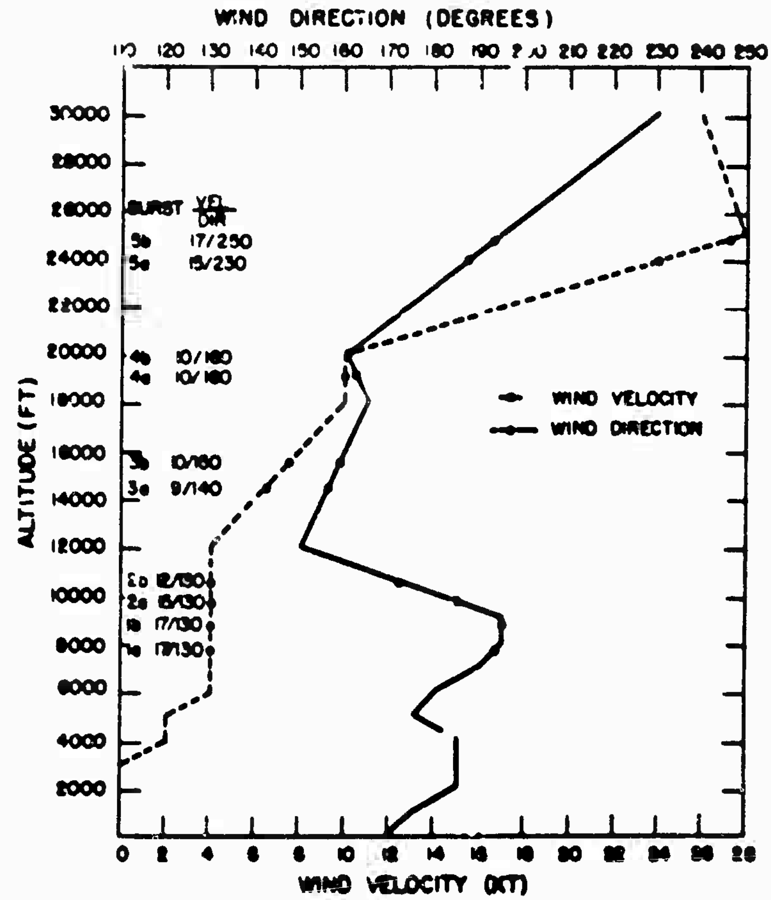

Fig. A.4—Wind direction and velocity vs altitude.

Table A.3—AMBIENT PRESSURE AND DENSITY AT GUN-BURST ALTITUDES

Burst	Altitude, ft	Ambient pressure, psi	Ambient density, g/liter
1a	7,780	11.1	0.920
1b	8,770	10.75	0.904
2a	9,600	10.4	0.878
2b	10,400	10.1	0.858
3a	14,400	8.6	0.781
3b	15,400	8.3	0.727
4a	19,140	7.4	0.638
4b	20,000	7.1	0.615
5a	23,900	6.0	0.544
5b	24,700	5.8	0.531

[redacted]

APPENDIX B

BALLISTICS FOR GUN BURST 5a

The intersection of two planes defined the line along which the gun bursts would occur (see Sec. 3.3). Figure B.1 illustrates the location of gun burst 5a (the bursts were labeled as pairs, and 5a corresponds to the burst at an altitude of 25,000 ft). The coordinates of this burst, for it to occur at the defined point, were determined as follows:

From Fig. B.1

$$u = \frac{A}{\tan \phi} = \frac{25,000}{\tan 60^\circ} = 14,430 \text{ ft}$$

$$x = A \tan \phi = 25,000 \tan 15^\circ = 6698 \text{ ft}$$

$$\alpha = \tan^{-1} \frac{x}{u} = \tan^{-1} (0.4640) = 24^\circ 54'$$

$$y = \frac{x}{\sin \alpha} = 15,900 \text{ ft}$$

Figure B.3 shows the plan view of zero island and burst 5a. From the known coordinates of the zero island and the angle α and distance y computed above, the coordinates of the gun burst are found.

$$\Delta N = y \sin (\alpha + \beta) = 15,900(0.7321) = 11,640$$

$$\Delta E = y \cos (\alpha + \beta) = 15,900(0.6813) = 10,830$$

$$N\ 147750 - \Delta N = N\ 136110$$

$$E\ 67790 + \Delta E = E\ 78620$$

The gun at Station 623.02 was to fire the projectile producing burst 5a. The coordinates of this gun station were N 143860 and E 86757.

From the geometry of the gun station in relation to the gun-burst position and the zero island,

Horizontal range (gun to burst), 3763 yd

Position angle, 68°41′

Slant range, 9145 yd

Train angle, 88°13′ left of bomb zero

[redacted]

[redacted]

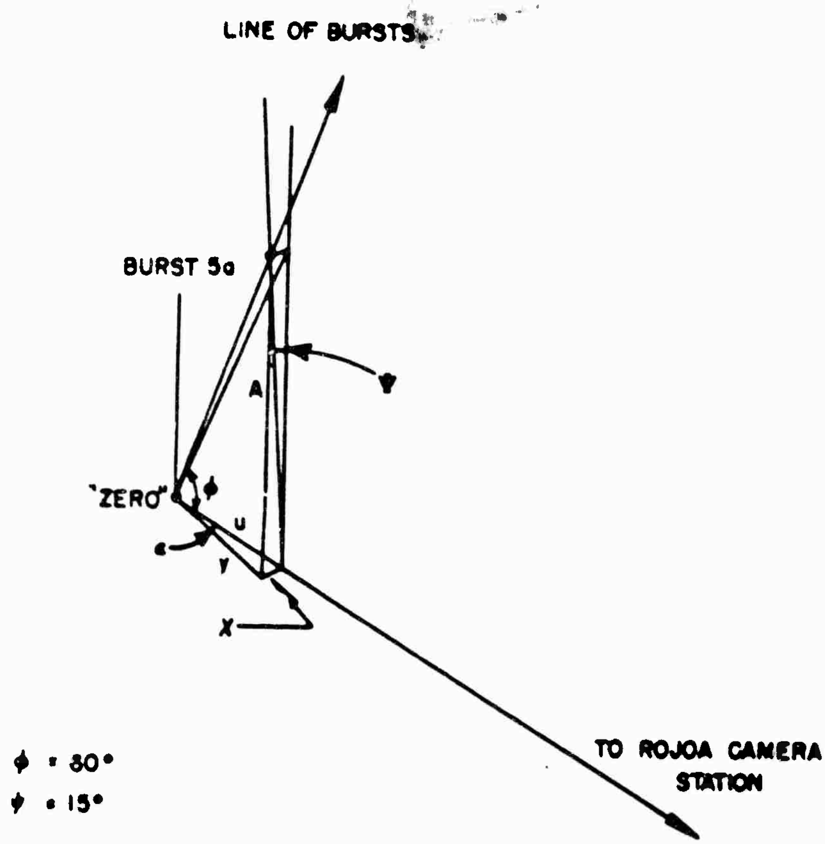

Fig. B.1—Position of gun burst 5a.

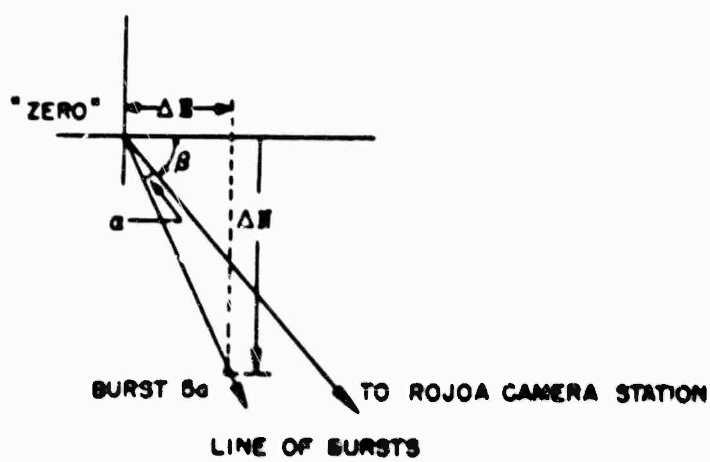

Fig. B.2—"Zero" and burst 5a in plan.

[redacted]

[redacted]

From OP-1766 (reference 1), for a slant range of 9145 yd and a position angle of 65°41′, the sight angle is 5°26′, and the time of flight is 24.40 sec. Since the elevation is the sum of the position angle and the sight angle,

Elevation angle, 71°07′

Under the standard conditions of the Range Tables the foregoing setting of train, elevation, and fuze (time of flight) would produce a burst at the desired coordinates, within the arbitrary ballistic error of ±20 yd in three dimensions.

A correction for drift of 20 yd right increases the train angle by 07′ to compensate; the train angle is now 55°30′.

Since the gun has an initial velocity characteristic of 2700 ft/sec and the Range Tables are computed for 2650 ft/sec, an increase in initial velocity of 50 ft/sec would result in the burst occurring 48 yd beyond in range and 149 yd high. To correct for the velocity increase, the sight angle is decreased 22′, and the time of flight is decreased 1.00 sec; the elevation is now 70°45′, and the fuze setting is 23.40 sec.

An assumed 10 per cent decrease in density would result in a burst 141 yd beyond and 396 yd high. To correct for this density change, the sight angle is decreased by 52′, and the time of flight is decreased by 2.52 sec; the elevation is now 69°53′, and the fuze setting is 20.88 sec.

An assumed 10-knot rear wind would result in a burst 37 yd beyond in range and 7 yd high. To correct, the sight angle is increased by 14′ and the time of flight by 0.15 sec.

After these corrections, the train is 55°20′, the elevation 70°07′, and the fuze setting 20.4 sec. If all assumptions are correct, the burst will occur in its desired position. If no corrections were made (and they should have been made), the error in range would be 250 yd beyond and 550 yd high. Conversely, if the corrections are proper (and actual conditions required no correction), the error in range would be 250 yd short and 550 yd low in altitude. It may be seen from the foregoing that the probable position of the burst may vary within wide limits; however, the preshot ballistic computation indicated that, even under the most unfavorable conditions, the bursts would occur within the camera field of view, and the shot island and adjacent instrumented islands would suffer no damage during the gun-battery test firing.

The gun firing burst 5a was set at 55°20′ train, 70°07′ elevation, and 20.4-sec fuse, as computed in the preshot ballistic problem. Subsequent to Mike shot, when meteorological data were received, a second ballistic problem was solved to determine the true location of the burst. Ballistic wind and density were computed,[2] and for burst 5a it was found that a 10 per cent decrease in density, an effective 16-knot head wind, and a 6-knot cross wind (from left to right when viewed along the trajectory) would have to be applied to the preshot ballistic problem. In addition, a correction for a 20°F temperature increase was necessary. The corrections were made, according to OP-1766, with the following results:

6-knot cross wind, 30 yd right

16-knot head wind, 85 yd short
11 yd low

20°F temperature increase, 4 yd short
17 yd low

10 per cent decrease in density, 127 yd short
339 yd low

Total correction, 30 yd right
216 yd short
367 yd low

The burst actually occurred (after applying the foregoing corrections to the planned burst

[redacted]

[redacted]

coordinates) at an altitude of 23,900 ft instead of 26,000 ft. The true plan coordinates (after correcting for the range short of 216 yd and the deflection of 30 yd) of the burst were N 136623, E 79027; with the known coordinates of bomb zero the resultant true slant range of burst 5a from the zero island was 28,650 ft as compared to a planned slant range of 29,600 ft. Table B.1 summarizes the planned and actual altitudes and slant ranges of the gun bursts.

Table B.1 — SLANT RANGE AND ALTITUDE, GUN BURSTS

Burst	Planned altitude, ft	Planned slant range, ft	Actual altitude, ft	Actual slant range, ft
1a	6,000	10,220	7,780	10 160
1b	9,000	11,400	8,770	11,300
2a	10,000	11,850	9,680	11,690
2b	11,000	13,050	10,490	12,720
3a	15,000	17,750	14,460	17,410
3b	16,000	18,950	15,480	16,560
4a	20,000	23,700	19,140	23,000
4b	21,000	24,900	20,080	24,100
5a	25,000	29,600	23,900	28,650
5b	26,000	30,800	24,760	29,780

REFERENCES

1. OP-1766, AA Range Table for 3-inch, 50-caliber Gun. (All corrections are from this publication.)
2. NA-50-110R-26, Instructions and Tables for Making Observations and Computing Ballistic Wind and Ballistic Density.

[redacted]